Feasibility Study

Operable Unit 3, Horseshoe Road and Atlantic Resources Corporation Sites, Sayreville, New Jersey

Prepared for

ARC OU-3 Cooperating Group
Newark, New Jersey

100077

Exponent®

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Prepared for

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Contents

Page

Page

List of Figures

Figures are presented at the end of the main text.

List of Tables

Tables are presented at the end of the main text.

Acronyms and Abbreviations

ADC	Atlantic Development Corporation
AET	apparent effects threshold
AOC	area of concern
ARAR	applicable or relevant and appropriate requirement
ARC	Atlantic Resources Corporation
BERA	baseline ecological risk assessment
CDM	CDM Federal Programs
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980
CoPC	chemical of potential concern
Corps	U.S. Army Corps of Engineers
EPA	U.S. Environmental Protection Agency
HHRA	human health risk assessment
HRDD	Horseshoe Road Drum Dump
LOAEL	lowest-observed-adverse-effects level
MCUA	Middlesex County Utilities Authority
MNR	monitored natural recovery
NCP	National Contingency Plan
NJDEP	New Jersey Department of Environmental Protection
NPL	National Priorities List
OU-3	Operable Unit 3
PCB	polychlorinated biphenyl
ppt	parts per thousand
PRG	preliminary remediation goal
RAO	remedial action objective
the river	Raritan River
ROD	record of decision
the Sites	Operable Unit 3 of the Horseshoe Road and Atlantic Resources Corporation Superfund Sites
SLERA	screening-level ecological risk assessment
SPD	Sayreville Pesticide Dump
TBC	to be considered

1 Introduction

The purpose of this feasibility study is to develop and evaluate remedial alternatives applicable to Operable Unit 3 (OU-3) of the Horseshoe Road and Atlantic Resources Corporation (ARC) Superfund Sites (collectively, the Sites) located in Sayreville, Middlesex County, New Jersey. OU-3 includes sediments in the marsh and intertidal portions of the Raritan River (the river) that are adjacent to the Sites. Exponent has performed this work on behalf of a group of cooperating parties under an Administrative Order on Consent (CERCLA-02-2003-2033).

The feasibility study is organized according to U.S. Environmental Protection Agency (EPA) guidance for Superfund studies (U.S. EPA 1988). It incorporates information from two previous submittals to EPA (*Identification of Candidate Remedial Technologies* [Exponent 2005] and *Development of Remedial Alternatives* [Exponent 2006b]) as well as a June 11, 2007, letter (June letter) from EPA regarding remedial action objectives (RAOs), remediation goals, and other remedial considerations (Prince 2007a, pers. comm.) and comments from EPA on the draft feasibility study report (December letter; Prince 2007b, pers. comm.).

This first section of the feasibility study describes the Sites and their regulatory history, the physical characteristics of OU-3, the nature and extent of contamination, as well as a summary of ecological and human health risks at OU-3. Sections 2 through 7 of this report are organized as follows:

- Section 2—*Identification and Development of ARARs, RAOs, and Remediation Goals*
- Section 3—*Remedial Technology Screening and Assembly of Alternatives*
- Section 4—*Development of Remedial Alternatives*
- Section 5—*Individual Analysis of Alternatives*
- Section 6—*Comparative Analysis between Alternatives*
- Section 7—*Summary*
- Section 8—*References*.

Appendices A through D include applicable or relevant and appropriate requirements (ARARs), ecological preliminary remediation goals (PRGs), flood scour analysis, and geochemical modeling, respectively. Appendix E contains the detailed cost estimates, Appendix F technology applications for OU-3, and Appendix G contains a statistical analysis of mercury concentrations in river sediment.

1.1 Site Description

The Horseshoe Road and ARC Sites together consist of four properties located in Sayreville, New Jersey. A vicinity map is provided in Figure 1-1, and a map of the Sites is included as Figure 1-2. Three of the properties (i.e., the Horseshoe Road Drum Dump [HRDD], the Atlantic Development Corporation [ADC], and the Sayreville Pesticide Dump [SPD]) are grouped together and considered as one site (the Horseshoe Road Site) on the National Priorities List (NPL). The Horseshoe Road Site is 12 acres in size. The fourth property, ARC, is 4.5 acres. It is located adjacent to the Horseshoe Road Site, and is also listed separately on the NPL.

The Sites are located on the southeast shore of the Raritan River and are bordered to the east by the Kearny Branch of the Raritan River Railroad (Conrail) and to the southeast by woods that separate the Sites from a residential neighborhood (approximately 0.5 miles away). Property to the west and south is currently undeveloped and includes a wetland and an area that was formerly used for disposal of dredged material from shipping lanes in the Raritan River (U.S. EPA 2004). Property owned by the Middlesex County Utilities Authority (MCUA) borders the Sites to the north and on the other side of the railroad tracks to the east.

The area surrounding the Sites is used for both residential and industrial purposes. While there are single-family homes and multi-residence buildings in the vicinity, in general, the area is industrial/commercial in character. Co-Steel Corporation operates a facility approximately 0.5 miles to the southwest. MCUA operates a wastewater treatment plant north of the Sites, and an MCUA trunk line and maintenance right-of-way cut through the ARC and ADC properties. The former NL Industries remediation site is also located to the north of the Sites along the Raritan River. Located approximately 3 miles upstream (southwest) of the Sites are three landfills that are no longer operating (the KinBuc landfill Superfund site, the Edison Township municipal landfill, and the ILR landfill), and the Middlesex County landfill, which continues to operate.

Various operations were conducted at the Sites over more than 30 years. The HRDD was used from approximately 1972 to the early 1980s for disposal. The ADC site contained three buildings and was active from the early 1950s until the late 1970s, with limited operations into the early 1980s. At different times, operations at ADC included production of roofing materials, sealants, polymers, urethane and epoxy resins, resin pigments, wetting agents, pesticide intermediates, and recycled chlorinated solvents (U.S. EPA 2004). The SPD was used for disposal from 1957 through the early 1980s and was named for alleged disposal of pesticides. It is not clear when operations began at the ARC site (CDM 1999a). Various operations, including precious-metal recovery, were alleged to occur between the late 1960s and the early 1980s. In addition, solvents and other materials were used to fuel the incinerators for the operations. From 1985 to the early 1990s, EPA conducted ten removal actions at the Sites. These actions included drum removal, spill cleanup, disposal of material found in vats and storage tanks at the Sites, and excavation and disposal of contaminated material and debris (U.S. EPA 2004).

1.2 Site Regulatory History

EPA proposed the Horseshoe Road Site for inclusion on the NPL on May 10, 1993 but, as discussed in Section 1.1, EPA had already conducted several removal actions, starting in 1985 (with drum removal at the HRDD as requested by the New Jersey Department of Environmental Protection [NJDEP] [CDM 1999a]). In February 1995, the New Jersey Department of Health issued a preliminary health assessment, which concluded that site conditions represented an indeterminate health hazard. The Horseshoe Road Site was formally placed on the NPL on September 29, 1995.

In October 1997, EPA's contractor, CDM Federal Programs (CDM), initiated remedial investigation activities at the Horseshoe Road Site. ARC was initially included in the description of the Horseshoe Road Site, but it was later removed and subsequently listed as a separate NPL site. ARC was proposed for inclusion on the NPL on September 25, 2001, and was formally listed on September 5, 2002.

EPA has organized the work on the Sites into three Operable Units:

- OU-1: Demolition of buildings and aboveground structures at both the ARC and ADC properties
- OU-2: Contaminated soil and groundwater at the Sites
- OU-3: River and marsh sediment.

The final remedial investigation report for the Horseshoe Road and ARC Sites was completed in May 1999 (CDM 1999a) and a focused feasibility study for OU-1 was completed in September 1999 (CDM 1999b). EPA issued a record of decision (ROD) for OU-1 in September 2000. EPA demolished buildings associated with the ADC site pursuant to the OU-1 ROD. A group of cooperating parties (including many of the parties participating in the OU-3 Cooperating Group) demolished the ARC buildings pursuant to an Administrative Order on Consent (Index No. II-CERCLA-02-2001-2021) with an effective date of November 8, 2001. In addition, ancillary facilities at the ARC site were removed (e.g., baghouse filters, incinerators), along with three underground storage tanks. OU-1 demolition activities were completed in 2003. The Sites are currently vacant property.

The feasibility study for OU-2 was issued in September 2002 (CDM 2002a), and addenda were issued in July 2003 (CDM 2003) and January 2004 (CDM 2004). The July 2003 addendum addressed the technical impracticability issues associated with the limited potential for groundwater contaminant migration at the Sites. The January 2004 addendum revised the remedial alternatives and associated cost estimates to reflect the changes resulting from the technical impracticability determination.

The ROD for OU-2 was issued September 30, 2004 (U.S. EPA 2004), and required remediation of soils at the Sites. For each of the properties, arsenic and/or polychlorinated biphenyls (PCBs) in soils were identified as contributors to human health risk. On the ADC property, benzo[a]pyrene and 1,2-dichloroethane were also identified as contributors to human health risk for surface (i.e., above the groundwater table) and subsurface (i.e., below the groundwater table) soil, respectively. The ROD estimates that remediation will include excavation of approximately 46,000 yd^3 of surface soil and debris, and approximately 16,000 yd^3 of subsurface soil from the SPD, ADC, and HRDD areas and the ARC site, followed by backfilling and grading. All contaminated soil, debris, and Resource Conservation and Recovery Act-hazardous waste will be transported, treated as necessary, and disposed offsite. The excavation is expected to be conducted in early 2009 and must occur prior to any work at OU-3 to avoid recontamination of OU-3 sediments.

The OU-2 ROD did not require groundwater action because of the technical impracticability determination; however, excavation of contaminated soil is expected to reduce the potential contaminant load to groundwater. Long-term groundwater sampling and analysis will be conducted at the Sites to monitor the nature and extent of contamination, and to assess possible migration and attenuation. In addition, well installation and groundwater use will be restricted through institutional controls (e.g., Classification Exception Area and/or Well Restriction Area).

In 2003, a group of cooperating parties (i.e., the OU-3 Cooperating Group) signed an Administrative Order on Consent to conduct a supplemental field investigation, baseline ecological risk assessment (BERA), and feasibility study for OU-3. The supplemental field investigation was conducted in 2004 and results were incorporated into the BERA (Exponent 2006a), which EPA approved in November 2006. This document presents the screening of remedial technologies and development of remedial alternatives for OU-3.

1.3 Physical and Ecological Characteristics of the Site

OU-3 consists of sediments in both the freshwater marsh and intertidal portion of the Raritan River located adjacent to the Sites. Information on surface water hydrology, geology and hydrogeology, and ecology from the remedial investigation report (CDM 1999a), the feasibility study report (CDM 2002a), the screening-level ecological risk assessment (SLERA) addendum (CDM 2002b), and the BERA (Exponent 2006a) is summarized in this section.

1.3.1 Surface Water Hydrology

The topography of OU-3 is relatively flat, with a slight grade toward the river. The majority of surface water at the Sites travels through three drainage channels that originate in the upland areas and flow from southeast to northwest through the marsh toward the Raritan River. NJDEP classifies the water in these channels as FW2-NT (i.e., freshwater 2, not for trout production or maintenance). The salinity of water in these channels ranges from zero to 0.8 parts per thousand (ppt), which NJDEP considers to be fresh water because it is less than 3.5 ppt (N.J.A.C. 7:9B).

Three main drainage channels convey surface water from the upland portions of the Sites to the marsh area. These channels are located between the SPD and ADC properties (SPD/ADC drainage), between the ADC and ARC properties and the southwest side of the HRDD (ADC/ARC/HRDD drainage), and north of the ARC property on the northeast of the HRDD (ARC/HRDD drainage) (Figure 1-2). The drainages are visible as channels or streams, particularly during wet weather. Observations and measurements of these channels were made during the remedial investigation, as reported by CDM (1999a). As noted in the remedial investigation report (CDM 1999a) and the ROD for OU-2 (U.S. EPA 2004), these drainage channels act as conduits for contaminant transport from the OU-2 operation areas to the downgradient marsh and river (OU-3). Thus, remediation of OU-2 will have to occur prior to remedial work in OU-3 to avoid recontamination of OU-3 sediments.

The SPD/ADC drainage channel is formed as several branches from the SPD and ADC sites converge and then flow through an underground culvert to the marsh and the Raritan River (CDM 1999a). The channel has some water flowing in it throughout the year and therefore appears to be perennial. The channel is shallow with usually 1 in. or less of water, 2 to 5 ft in width, and has a silt and/or clay bottom. The pH of water in the channel ranges from 4.64 to 7.02.

The remaining two drainage channels are intermittent in nature and their use is limited to species that can survive when the channel dries up (CDM 1999a). The ADC/ARC/HRDD drainage channel is located between the ADC and ARC properties. It is visible along the west side of the HRDD before entering the marsh area, crossing the tidal flats, and terminating at the Raritan River (CDM 1999a) near the river-side end of the small embayment at the north side of the marsh. A drafting pond, reportedly used historically for non-contact cooling water, is located on the ADC property in the east-central portion of the Sites and may contribute flow to this drainage. Flow in the channel is intermittent. The channel is less than 6 in. in depth, 1 to 4 ft in width, and has a silt and/or clay bottom covered in leaf litter. The pH of water in this channel ranges from 6.68 to 6.92.

The ARC/HRDD drainage channel is located along the northeast side of the HRDD. It is visible entering the tidal flats and terminating at the Raritan River (CDM 1999a) at a point approximately halfway to the end of the small embayment at the north side of the marsh. Flow is intermittent and the channel is often dry. The channel is shallow, 2 to 5 ft in width, and has a silt and/or clay bottom. The pH of water in this channel ranges from 4.92 to 7.52.

The Raritan River is the largest surface water feature associated with OU-3. At this location, NJDEP classifies the water of the Raritan as SE1 (i.e., saline estuarine 1). The salinity of the river ranges from 5 to 6 ppt as measured at the bank of the river adjacent to the marsh (CDM 1999a). This portion of the Raritan River experiences bidirectional flow as a result of tidal cycles; the outlet to Raritan Bay is to the northeast. A small embayment is present at the north side of the marsh.

During periods of high water in the Raritan River (e.g., following heavy rainfall), the marsh area may become inundated with river water, as observed just prior to the supplemental field investigation in September 2004. With the exception of these flood conditions, the marsh is not generally inundated with river water, even during high tide. Tidal inundation is limited to the intertidal zone, which consists of a narrow band of salt-tolerant cordgrass (*Spartina alternifolia*) and unvegetated mud flats (i.e., tidal flats) at the edge of the Raritan River. Virtually the entire OU-3 area lies within the 100-year floodplain, with much of the marsh elevated only a foot or two above the river (Figure 1-3).

1.3.2 Geology and Hydrogeology

From a geological perspective, the Sites, including the upland areas and OU-3, are located on top of the Woodbridge Unit, which is a regional aquiclude (i.e., a subsurface rock, soil, or sediment unit that may absorb water slowly but does not yield useful quantities of water) that is more than 100 ft thick (CDM 1999a). The Woodbridge Unit is underlain by Triassic diabase sill, which is essentially impermeable. The two regional aquifers (Old Bridge and Farrington) are geologically isolated from the Sites.

The Woodbridge Unit consists of gray silt and clay, with occasional discontinuous lenses of fine sand and silt in the upper 50 to 60 ft. In the top 30 ft of the Woodbridge Unit, the laterally discontinuous gray fine sand layers range in thickness from 2 to 8 ft, and are separated by layers of gray/dark gray laminated silts and clays (CDM 1999a). These layers were visible in soil borings taken during the remedial investigation. The subsurface silt and clay of the Woodbridge Unit have very low permeability, and groundwater flow is restricted to the sand lenses, which are discontinuous.

The low hydraulic conductivity and specific capacity of the shallow aquifer, in combination with the hydraulic isolation of site groundwater from the regional supply aquifer, were the basis for the justification of technical impracticability in the ROD. Under these conditions in the shallow aquifer, groundwater extraction and treatment would not expedite cleanup of the groundwater, and the shallow aquifer could not be used for drinking water because it cannot sustain pumping (CDM 2003). Slow groundwater velocities and the high organic carbon content and geochemistry of the aquifer matrix retard downgradient transport of contaminants from the Sites (CDM 2003). The ROD also cited the SLERA addendum’s finding of a lack of any significant risks to the environment associated with groundwater discharges to the marsh.

1.3.3 Ecology

The remedial investigation report classifies the marsh as an EW3 emergent wetland area (CDM 1999a). The dominant vegetation is a dense, nearly pure stand of non-native common reed (*Phragmites communis*) bordered by a nearly pure stand of the more salt-tolerant native cordgrass (*Spartina alternifolia*) in the intertidal zone next to the mud flats along the edge of the Raritan River. Tidal flats border the northern and western edges of the marsh along the river. Figure 1-2 shows the approximate extent of *Phragmites* and the location of the cordgrass. Scrub-shrub habitat and upland forest border the *Phragmites* (CDM 1999a).

The SLERA addendum considered areas of the Sites other than the marsh to provide more favorable habitat for small mammals than the marsh itself (CDM 2002b). Generally, *Phragmites* is considered an invasive species, and *Phragmites* marshes provide low-quality nesting and foraging habitat for mammals. Small-mammal trapping in 2004 yielded deer mice (*Peromyscus maniculatus*); however, the traps were set at the edges of the *Phragmites* where habitat was considered more suitable. Short-tailed shrews, which were used as ecological receptors in the BERA food-web model, were not observed at the site.

1.4 Summary of Contaminant Transport and Fate

The results of the supplemental field investigation in 2004 supported earlier conclusions regarding the nature and extent of contamination in OU-3 and the transport and fate of contaminants. The primary transport pathway from OU-2 to OU-3 identified in the remedial investigation report (CDM 1999a) and the ROD for OU-2 (U.S. EPA 2004) is surface runoff that flows through drainage channels into the marsh, and ultimately to the Raritan River. The contaminants of concern in this surface water runoff (i.e., arsenic, mercury, and PCBs) adsorb to suspended sediment in the water and then accumulate where sediments are deposited or are transported when sediment becomes resuspended. These contaminants are considered to be persistent because of low solubility or very slow biodegradation rates. Concentrations in soils and sediments at the Sites are predicted to remain stable or decrease slowly over time, as contaminated sediment moves farther down the drainage channel to the marsh and river and mixes with relatively cleaner sediment also deposited at the surface.

The historical and 2004 data highlighted the importance of the SPD/ADC drainage channel as a primary conduit of arsenic, mercury, and PCBs from upland areas of the Sites into the marsh and the Raritan River (see Figures 1-4 and 1-5 for arsenic and mercury, respectively). Concentrations of these contaminants were substantially lower in sediments associated with the ADC/ARC/HRDD and the ARC/HRDD drainages and areas in the marsh downstream of these drainages. Few samples were collected between the drainages. Additional data collection during design will be required for delineation.

Arsenic, mercury, and PCB concentrations remained elevated in the SPD/ADC drainage for quite a distance into the marsh before decreasing and were generally much lower in river surface sediment than in the surface sediment of the SPD/ADC drainage. The highest concentrations of these contaminants in river sediment were generally observed near where the SPD/ADC drainage enters the river. Concentrations of arsenic and mercury tend to be highest at the surface in the SPD/ADC drainage sediment and river sediment at the mouth of the SPD/ADC drainage, indicating that the drainage continues to act as a source of contamination.

1.5 Conceptual Site Model

The conceptual site model for OU-3 includes three key characteristics that impact the selection of remedial alternatives. First, surface runoff from OU-2 contaminated and may continue to contaminate OU-3, particularly through the one perennial drainage (i.e., the SPD/ADC drainage). Thus, OU-2 remediation is required prior to OU-3 remediation to ensure that recontamination does not occur. Second, the SPD/ADC drainage is an ongoing source of arsenic, mercury, and PCBs to other areas of the marsh and the Raritan River. In addition, there are a few areas of elevated arsenic and mercury concentrations within the marsh (e.g., Stations SDM04, SD33) that have the potential to contaminate the marsh and river.

Third, sediments in the marsh and river are stable. Stations SDM09, SDM10, and SDM11 in the marsh and Stations RSD03, RSD04, RSD05, RSD07, RSD08, RSD11, RSD12, and RSD13 in the river have lower arsenic concentrations in the surface interval than in the subsurface interval directly below. Contaminant concentration patterns such as these suggest the potential for natural recovery of the sediments, likely as a result of sedimentation by particles with lower contaminant concentrations (see Appendix F). These stations are generally the farthest removed from the source area (i.e., the SPD/ADC drainage), with the exception of stations near (RSD14) and in the embayment (RSD16, RSD17, and RSD20), and therefore reflect the potential for recovery following source removal. Mercury concentrations follow a similar trend with Stations SDM10 and SDM11 in the marsh and Stations RSD03, RSD04, RSD05, RSD06, RSD08, RSD10, RSD13, and RSD15 having lower mercury concentrations in the surface interval than in the subsurface interval directly below. The fact that surface concentrations are lower than subsurface concentrations at numerous locations may reflect reduced loading of contaminants from OU-2 following closure of the facilities; however, contamination in SPD/ADC drainage is likely an ongoing, albeit smaller, source.

The potential for natural recovery in the marsh and river is supported by the estimation of scour velocities required to resuspend sediment in the marsh and river (see Appendix C). As discussed in Appendix C, these sediments are non-uniform and contain fine-grained sediment fractions, both of which result in cohesive sediment. Because cohesive sediments consolidate with time, bed sediments become less susceptible to erosion with depth of sediment. In addition, for a certain shear stress, only a finite amount of sediment can erode. Marshes, in general, are depositional regions where surface water flow rates tend to be low and suspended particles settle out. *Phragmites* marshes, in particular, have been identified as having elevated rates of deposition because of abundant plant litter accumulation (Rooth and Stevenson 2000). Even without considering the beneficial effect of marsh vegetation in retarding flow, encouraging deposition, and thus enhancing sediment stability, marsh and river sediments in OU-3 are unlikely to become resuspended during 100-year flood conditions in the Raritan River. Sediment stability is important as it allows the process of natural recovery to occur, following source removal.

The presence of arsenic concentrations greater then 100 mg/kg at the deepest interval sampled (30–42 in.) in the marsh and river has been noted. While sediment deposition can account for some burial, the depth of this contamination suggests that another mechanism such as downward migration of soluble arsenic species is or was operative. As described in Appendix D, dissolution and migration of arsenic occurs under reducing conditions. Such a mechanism is not likely to be a major transport mechanism within the site because of the low hydraulic conductivity of the marsh sediments and relatively flat groundwater gradients, but it can cause downward migration resulting in elevated concentrations at depth.

1.6 Summary of Ecological Risks

The BERA (Exponent 2006a) investigated risks to various components of the ecological community in the OU-3 marsh and adjoining Raritan River. The following assessment endpoints were evaluated:

- Aquatic and terrestrial invertebrate community abundance and population production
- Estuarine fish population abundance and community structure
- Abundance of avian and mammalian populations.

The measurement endpoints included sediment toxicity tests to assess potential risk to aquatic macroinvertebrates and terrestrial invertebrates (blackworms and earthworms, respectively), concentrations of chemicals of potential concern (CoPCs) in estuarine fishes compared to literature-based effect-level thresholds to assess potential risk to estuarine fishes, and food-web modeling to assess potential risk to birds and mammals.

In the OU-3 marsh, the BERA found that, while there is little potential for widespread adverse effects on survival of (i.e., lethal toxicity to) aquatic and terrestrial invertebrates, there is a potential for adverse effects on growth of (i.e., biomass reduction in) individual aquatic and terrestrial invertebrates in localized areas. Risks of sublethal growth effects were greatest in the SPD/ADC and ADC/ARC/HRDD drainage channels, where contaminant concentrations were the highest. The BERA noted that the lethal and sublethal effects observed in the blackworm and earthworm tests were conservatively assumed to be a function solely of chemical concentrations in marsh sediments. However, other factors may influence both survival and growth of these organisms in the test chambers and the field, such as the natural characteristics of the site sediments (e.g., moisture content, grain size distribution, total organic carbon concentration, and quality). Because the marsh sediments in the study area are located in a transitional environment between true aquatic and true terrestrial environments, it is possible that their natural characteristics were not optimal for the aquatic blackworms and terrestrial earthworms used as test organisms in this study. The effects of such suboptimal conditions would most likely be manifested as sublethal effects (e.g., biomass reductions) in the toxicity tests, rather than as lethal effects.

The BERA also identified the potential for adverse effects on individuals of avian and mammalian invertivore receptor species in the drainage channels of the marsh, where contaminant concentrations are elevated. In particular, arsenic, mercury, and/or PCBs were identified as the primary risk drivers for these receptors. For mammalian herbivore receptors that are assumed to forage over the entire marsh, risks were calculated to be relatively low and to result primarily from arsenic and mercury. Calculated risks were negligible for avian carnivores with home ranges larger than the area of the marsh.

While potential risks were identified for individual invertebrates as well as some individual avian and mammalian receptors, it is uncertain if these potential risks translate to population-level effects, which are the assessment endpoints. There is additional uncertainty to the extent that risks estimated from sediment data collected primarily in drainage channels are translated to the entire marsh or to areas of the marsh between drainage channels, where few samples were collected and contaminant concentrations are likely to be lower. For example, short-tailed shrew is not expected to forage in sediment with overlying water as in the SPD/ADC drainage. Also, while CoPC concentrations may be an important factor on a localized basis, factors such as the suitability of periodically inundated and primarily *Phragmites* marsh as habitat for receptors, particularly shrews and other small mammals, may be important determinants of population abundance and distribution when the OU-3 marsh is considered as a whole.

In the Raritan River portion of OU-3, the BERA found that there is a negligible likelihood of adverse effects to fish and wildlife populations. The SLERA addendum (CDM 2002b) noted the potential for localized adverse effects on benthic organisms from contaminated Raritan River sediment in the area immediately adjacent to where the main drainage channel for the marsh (i.e., the SPD/ADC drainage) enters the river. This conclusion was based on the statistically lower survival rate of a benthic organism at one station (of the four tested) to the reference station.

1.7 Summary of Human Health Risks

A human health risk assessment (HHRA) was conducted in 1999 for six areas of concern (AOCs) at the Horseshoe Road Complex Site (CDM 1999c). Two of these AOCs, the downstream marsh and the Raritan River adjacent to the Sites, are now termed OU-3, which is the subject of this document. The HHRA evaluated current and future risks to area residents (trespassers) who might come into direct contact with surface water and sediment during recreational activities in the downstream marsh and Raritan River (OU-3). Ingestion of and dermal contact with surface water and sediment were identified as potential exposure routes.

In both the downstream marsh and the Raritan River, the total noncarcinogenic hazard index exceeded 1.0 for area residents (trespassers). The hazard index exceedance was attributed to arsenic in sediment. In both AOCs, the total carcinogenic risk did not exceed 10^{-4} for area residents (trespassers).

2 Identification and Development of ARARs, RAOs, and Remediation Goals

This section identifies potential ARARs, RAOs, and remediation goals for OU-3. Then, using selected remediation goals, estimates are developed for the area and volume of marsh and river sediment to be remediated.

2.1 Applicable or Relevant and Appropriate Requirements

Alternatives are evaluated to determine whether they attain chemical-specific, location-specific, and action-specific ARARs under federal and state environmental laws. A detailed summary of ARARs and to be considered (TBC) criteria is provided in Appendix A (Table A-1). A detailed evaluation of the ability of remedial alternatives to comply with relevant ARARs and TBCs is performed in Section 5 (*Individual Analysis of Alternatives*) and Section 6 (*Comparative Analysis Between Alternatives*). Remedial alternatives that do not meet relevant ARARs are not considered to be technically feasible.

2.2 Remedial Action Objectives

The overall remedial objective for contaminated sediment in OU-3 is to protect human health and the environment by eliminating exposure pathways and/or reducing the concentration of contaminants that pose risk. Specific RAOs for the marsh and river were developed to address potential risks identified in the BERA (Exponent 2006a) and HHRA (CDM 1999c) as follows:

- **RAO1—**Reduce to acceptable levels risks to human health from exposure to contaminants in surface and subsurface marsh sediments through ingestion, inhalation, and dermal contact
- **RAO2—**Reduce to acceptable levels risks to environmental receptors from exposure to contaminants in marsh sediments
- **RAO3—**Minimize the migration of contaminated sediments from the marsh to the Raritan River through surface water runoff or flooding
- **RAO4—**Reduce to acceptable levels the potential for human health risks from exposure through ingestion of or dermal contact with river sediments within the low tide mudflat
- **RAO5—**Reduce to acceptable levels risks to environmental receptors from exposure to contaminants in river sediments and, thereby, minimize migration of contaminated sediments to the Raritan River Estuary.

The marsh RAOs pertain to specific risks as follows:

- RAO1 addresses the potential risk to human health identified in the HHRA resulting from exposure to arsenic in marsh sediment.
- RAO2 addresses the potential risk to terrestrial and aquatic invertebrates, plant-eating mammals, and insect-eating birds identified in the BERA. This risk results primarily from exposure to arsenic, mercury, and/or PCBs in sediment, plants, or prey items.
- RAO3 addresses the potential for contaminated sediment, primarily in the SPD/ADC drainage, to be transported to other areas in the marsh and to the Raritan River through surface water runoff or flooding.

Similarly, the river RAOs pertain to specific risks as follows:

- RAO4 addresses the potential risk to human health identified in the HHRA as a result of exposure to arsenic in river sediment.
- RAO5 addresses the potential risk to aquatic benthic organisms identified in the SLERA addendum and the potential for contaminated river sediment to be transported to the Raritan River Estuary. Risk was noted to a limited extent for aquatic benthic organisms (CDM 2002b). No significant risks were found for fish or birds (Exponent 2006a).

2.3 Remediation Goals

Remediation goals are chemical-specific concentration goals used to evaluate and select remedial technologies and to develop remedial alternatives in a feasibility study. EPA guidance on remediation of contaminated sediment at hazardous waste sites (U.S. EPA 2005) recommends that remediation goals include a range of values within acceptable risk levels. At a later point, remediation goals are refined further into chemical-specific cleanup levels by weighing site-specific uncertainty factors as well as the National Contingency Plan (NCP) evaluation criteria for remedy selection (40 CFR 300). These criteria include overall protection of human health and the environment; compliance with ARARs; long-term effectiveness and performance; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; cost; and state and community acceptance. According to the contaminated sediment guidance (U.S. EPA 2005, p. 2-17), uncertainty factors that may be considered include "the reliability of inputs and outputs of any model used to estimate risks and establish cleanup levels, reliability of the potential approaches to achieve those results, and the likelihood of occurrence for the exposure scenarios being considered."

Sediment is the medium of interest at OU-3, because it contributes the majority of contaminant exposure for both humans and ecological receptors. Both the BERA and the HHRA identified arsenic as the primary contaminant of concern in marsh and river sediment. In addition, the BERA identified mercury and PCBs in marsh sediment as potentially significant contributors to estimated risks to ecological receptors. Elevated concentrations of PCBs co-occur with arsenic and mercury at OU-3 and addressing arsenic and mercury through remediation is expected to address potential risk related to PCB exposure (Exponent 2006a; Prince 2007a, pers. comm.).

2.3.1 Marsh Sediment Preliminary Remediation Goals

Marsh sediment PRGs for arsenic and mercury were considered to address risks to human health and ecological resources. Arsenic is potentially both a human health and an ecological concern in the marsh, but remediation is more likely to be driven by potential ecological risks because of limited human exposure in the marsh. Mercury does not pose a risk to human health in the marsh (CDM 1999c), and thus, presents only a potential ecological concern. For this reason, the selection of remediation goals for mercury focuses only on the consideration of ecological risks. While the development of remediation goals to protect human health is fairly straightforward, development of goals to protect ecological resources is complicated by consideration of multiple receptors, uncertainties in the food-web models, and evaluation of relevant endpoints (e.g., effects on individuals versus population abundance).

With respect to human health risks, trespassers are the primary receptor of concern, and arsenic is the only contaminant of concern. OU-3 has limited accessibility for visitors, it is in the 100-year floodplain, and development is unlikely. Any future development plans in the area are not anticipated to substantially change the size or character of the marsh (Prince 2007a, pers. comm.). The trespasser PRG for arsenic (2,000 mg/kg) was developed in the HHRA for the Horseshoe Road Complex Site (CDM 1999c) using the exposure model from the HHRA. It was calculated to be protective of trespassers who are exposed to marsh or river sediment by dermal contact or incidental ingestion and is included in Table 2-1.

In contrast to human health, where the primary risk concern is for one receptor (i.e., trespasser), numerous ecological receptors were evaluated at OU-3, each experiencing different exposure, susceptibility, and risk. However, the potential use of OU-3 by various receptors needs to be factored into the development of remediation goals. Use of the marsh is likely to be limited for some of the receptors evaluated in the BERA. For example, as discussed in the SLERA addendum (CDM 2002b), small mammals are unlikely to reside in the marsh, especially with more favorable habitat located adjacent to the marsh. In general, *Phragmites* marshes are considered to provide low-quality nesting and foraging habitat for mammals. Given the low likelihood that the shrew or other small mammals would reside exclusively in the marsh, PRGs for small mammals (e.g., the short-tailed shrew) were not developed.

The marsh is also not an ideal habitat for blackworms or earthworms because of water fluctuations associated with inundation during high flow events and the seasonal wet/dry cycle (i.e., summer drawdown and winter reflooding). According to Bedford and Powell (2005), *Phragmites* marshes are characterized by low species diversity and reduced numbers of invertebrates resulting from the disruption of periodic submergence and exposure. Blackworms are typically found in muddy sediments, especially in shallow water along the edges of marshes and ponds. They feed on submerged leaves and decaying matter and breathe through their skin (i.e., respire dissolved oxygen from the water) (Drewes 2004). Based on the aquatic nature of this organism, it is expected to be found only in drainage features or ponded areas of the marsh where water and saturated sediments are present. The blackworm is not expected to inhabit the vast majority of the marsh, where inundation is infrequent and standing water is typically absent. These higher elevation areas of the marsh are considered terrestrial environments, with respect to invertebrate habitat, and would favor terrestrial invertebrates such as the earthworm.

Site-specific apparent effects thresholds (AETs) developed in the BERA (Exponent 2006a) were considered for development of PRGs. The AETs are the concentrations above which adverse effects were always observed in laboratory bioassays. In the BERA, five measurement endpoints were evaluated as part of the bioassay testing:

- Blackworm biomass reduction (28-day)
- Earthworm biomass reduction (14-day and 28-day)
- Blackworm survival (10-day)
- Earthworm survival (14-day).

These AETs (with the exception of the 14-day earthworm biomass reduction because 28-day results were available) are included in Table 2-1. Given the preferred habitats of the blackworm and earthworm, the blackworm PRGs are most applicable to saturated sediment with overlying water, while the earthworm PRGs are applicable to the remainder of the marsh, which is more terrestrial. The only area in the marsh that consistently has overlying water is the SPD/ADC drainage (i.e., the only perennial drainage). Other drainages are intermittent and are not expected to support a robust population of aquatic invertebrates.

Regarding depth of exposure, invertebrates are generally limited to the top 6 in. to 1 ft of sediment or soil. For sediment, the top 6 in. is generally considered the biotic zone (NJDEP 1998) where most biological activity occurs. Core samples to a depth of 4 cm (approximately 2 in.) are typically used to evaluate marsh invertebrate communities because most infaunal organisms are contained in the upper few centimeters of marsh sediments (Wieser and Kanwisher 1961; Couell and Bell 1979; Angradi et al. 2001). For soil, the majority of terrestrial invertebrate (i.e., earthworm) activity is in the top foot of soil (Lee 1985). This is certainly the case in the OU-3 marsh because the depth to water table in the marsh is approximately 0 to 25 cm (i.e., within 1 ft of the sediment surface) according to Natural Resources Conservation Service mapping (http://websoilsurvey.nrcs.usda.gov/app/).

It should be noted that the lowest arsenic PRG (i.e., 32 mg/kg) is based on chronic effects (i.e., reduction in biomass) to individual blackworms and is considerably lower than PRGs established for protection of blackworm survival (i.e., 17,800 mg/kg arsenic) as well as effects on the earthworm and higher trophic level organisms. Under U.S. EPA (2002, 2005) regulatory guidance, remedial actions should be protective of local populations and communities of biota, not individual organisms. As a result, a PRG between the minimum and maximum AETs will likely be protective of the invertebrate community and meet RAO2, which is to reduce to acceptable levels risk to environmental receptors from exposure to contaminants in marsh sediment.

The marsh may provide suitable habitat for birds that consume invertebrates (modeled as the marsh wren in the BERA) and mammals that eat plants (modeled as the muskrat in the BERA).

Therefore, arsenic and mercury PRGs for these receptors were calculated based on food-web models used in the BERA and site-specific information (if available), as described in Appendix B. As discussed in the BERA, where uncertainty was identified during modeling, values were selected that would tend to maximize exposure or effect and therefore would be conservative in estimation of risk (Exponent 2006a). The muskrat PRG, in particular, remains uncertain and thus conservative because literature values were used for all parameters in the model.

For the marsh wren, primary exposure is through consumption of invertebrates, which are primarily active in the top 6 in. of sediment and soil. The marsh wren PRG, therefore, is most appropriately applied to this surface layer. The muskrat is exposed to contaminants through consumption of plant roots at or near the sediment surface; thus the muskrat PRG is relevant for the top 6 in. to 1 ft of marsh sediment. While muskrats are known to burrow, this activity (potentially resulting in incidental consumption of sediment) is not a significant exposure pathway because consumption is minimal. Finally, in terms of application of the muskrat PRG, the muskrat is unlikely to feed in one location in the marsh, so relevant concentrations that are considered protective are best based on an areal average, because individuals integrate exposure over an area larger than a single location.

In addition to the site-specific, risk-based PRGs, Table 2-1 includes PRGs provided by EPA (Prince 2007a, pers. comm.). These PRGs are 160 mg/kg arsenic for subsurface sediment to protect burrowing animals and 2 mg/kg mercury in surface sediment to protect benthic organisms from direct toxicity and other organisms from bioaccumulation. The 2 mg/kg mercury value is NJDEP’s screening value for freshwater sediment (NJDEP 1998) and is based on the Persaud et al. (1993) review of sediment toxicity to benthic organisms. According to NJDEP (1998):

> The ER-L and LEL screens were developed based on benthic community studies and do not directly address **biomagnification (food chain toxicity)** to water column species (fishes), birds, and mammals. However, values found to be protective of the food chain are generally similar (within an order of magnitude) to ER-L/LEL values. When **PCBs, organochlorine pesticides and mercury (Hg)** are found in sediments at or above these screens, potential wildlife risks exist and case-by-case evaluation is warranted.

Although the screening values (e.g., 2 mg/kg mercury) were exceeded, the BERA provided a site-specific risk assessment that yielded site-specific information on potential risks for the OU-3 marsh and PRGs that will be protective of invertebrates, birds, and mammals as discussed above. The EPA PRGs were also selected to reduce contaminant release to the Raritan River.

2.3.2 River Sediment Preliminary Remediation Goals

Human health PRGs for river sediment are the same as for marsh sediment (i.e., remediation goals for arsenic developed in the HHRA for the Horseshoe Road Complex Site), as shown in Table 2-2. As with the marsh sediments, human health remediation goals were not developed for mercury and PCBs, because these contaminants were not significant contributors to human health risk for OU-3 river sediment (CDM 1999c).

The BERA did not identify risks to fish, birds, or mammals associated with the OU-3 river sediment; therefore, PRGs for river sediment for these receptors are not presented in Table 2-2. The absence of site-related bioaccumulation effects for mercury, in particular, is supported by the similarity of average mercury concentrations in OU-3 river sediment and average concentrations at the reference locations and for Raritan River background conditions, as described in Appendix G. The average mercury concentration for the 23 surficial OU-3 river sediment samples is approximately 1.6 mg/kg. This concentration is statistically similar to the average concentration for the five site-specific reference locations (i.e., 1.3 mg/kg). The standard deviations associated with these data sets are 1.03 and 1.52, respectively. In addition, the average mercury concentration of 1.6 mg/kg for OU-3 river sediment is comparable to the average background sediment concentration of 1.4 mg/kg obtained by EPA from the U.S. Army Corps of Engineers (Corps) for the Raritan River. In other words, average concentrations of mercury in OU-3 river sediment are similar to background concentrations in the river.

The potential risk of sediment toxicity to benthic organisms was evaluated in the SLERA addendum (CDM 2002b). The addendum noted reduced survival for benthic organisms at one sediment station (of four tested), which was located near the mouth of the SPD/ADC drainage. CDM subsequently developed lowest-observed-adverse-effect levels (LOAELs) for arsenic and mercury based on the sediment toxicity data (Osolin 2007, pers. comm.). These LOAELs are included as PRGs in Table 2-2. These PRGs for protection of benthic organisms in river sediment are considerably lower than the human health PRG for arsenic and are therefore more likely to drive remediation in the river.

In addition to the site-specific, risk-based PRGs, Table 2-2 includes PRGs provided by EPA (Prince 2007a, pers. comm.). These PRGs are 100 mg/kg arsenic and 2.0 mg/kg mercury (to protect benthic organisms from direct toxicity and other organisms from bioaccumulation). The 100 mg/kg arsenic value is the maximum river reference concentration noted in the BERA (Exponent 2006a). The 2.0 mg/kg mercury value is NJDEP’s screening value for freshwater sediment (NJDEP 1998) and is based on the Persaud et al. (1993) review of sediment toxicity to benthic organisms. As stated previously, a site-specific risk assessment (Exponent 2006a) was conducted, as recommended by NJDEP when screening guidelines are exceeded (NJDEP 1998) and no significant risks to fish and birds due to mercury bioaccumulation were found.

3 Remedial Technology Screening and Assembly of Alternatives

This section describes the process followed to identify and screen remedial technologies potentially applicable to the OU-3 marsh and river sediments, and to assemble the retained technologies into a range of remedial alternatives that will be evaluated in detail.

3.1 General Response Actions and Remedial Technologies

The first step in the analysis of alternatives is to identify general response actions that might be taken to remediate the site. Each general response action may include several possible remedial technologies and each technology may include process options. General response actions and remedial technologies potentially suitable for addressing contaminated marsh and river sediments within OU-3 were previously identified (Exponent 2005). These response actions and technologies are shown in Tables 3-1 and 3-2 along with brief descriptions.

The general response actions and their associated technologies include the following:

- No Action (included as a general response action as required under Part 300.430 of the NCP)
- Institutional and engineering controls
- Containment (capping)
- *In situ* treatment (monitored natural attenuation/recovery, immobilization, and electrokinetic separation)
- Removal (dredging, excavation, phytoremediation)
- *Ex situ* treatment (dewatering, physical separation, electrokinetic separation, chemical extraction, thermal treatment, and immobilization)
- Disposal (confined aquatic disposal and onshore/upland disposal).

3.2 Screening of Remedial Technologies

The next step in the analysis of alternatives for a feasibility study is to screen the remedial technologies and their process options. The technology screening, based on effectiveness, implementability, and relative cost, serves to focus the feasibility study on technologies that are most suitable for OU-3 by eliminating those that are obviously inappropriate or infeasible. Exponent (2006b) previously screened remedial technologies and process options that may be appropriate for containing, removing, treating, and/or disposing of marsh and river sediments. The technology screening for marsh and river sediments is shown in Tables 3-1 and 3-2, respectively. In these tables, the retained technologies are highlighted in boldface, and for those technologies screened out, the rationale for not retaining them is provided.

For marsh sediments, the following general response actions and/or remedial technologies are retained for potential inclusion in remedial alternatives:

- No action
- Institutional and engineering controls
- Monitored natural recovery (MNR)
- Capping
- Excavation
- Disposal.

For river sediments, the following general response actions and/or remedial technologies are retained for potential inclusion in remedial alternatives:

- No action
- MNR
- Capping
- Dredging
- Disposal.

Additional description of the retained remedial technologies, beyond the summary descriptions provided in Table 3-1, is provided in Appendix F. Each of these technologies has been used successfully at other contaminated sediment sites and is expected to be effective for OU-3.

3.3 Identification of Remedial Alternatives

Retained technologies are then assembled into various remedial alternatives that are intended to achieve the RAOs for the site. Remedial alternatives previously presented in Exponent (2006b) were modified based on subsequent discussions and correspondence with EPA including the June letter (Prince 2007a, pers. comm.) and the December letter (Prince 2007b, pers. comm.). The remedial alternatives identified for marsh and river sediments are presented in Table 3-3. Conceptual design and implementation details for these alternatives are developed in Section 4 and the alternatives undergo detailed evaluation in Section 5.

The overall remedial approach involves excavation of the highly contaminated sediments within the SPD/ADC drainage channel combined with other remedial technologies to address residual risk to environmental receptors in the marsh and river. Excavation of the SPD/ADC drainage will eliminate the primary transport pathway of residual contaminants from the marsh to the river. The other remedial technologies (i.e., MNR, cover/capping, excavation/dredging) applied to the remaining marsh and river sediments will minimize or eliminate the potential for exposure to the residual contaminants that exceed PRGs. The most aggressive remedial actions are applied to the areas of highest contaminant concentrations and highest risk. The aggressiveness of the remedial actions is decreased in a step-wise fashion to address areas of lower contaminant concentrations corresponding to the various PRGs. This approach achieves the OU-3 RAOs and the PRGs with remedial measures employed to a degree proportionate to the level of risk.

4 Development of Remedial Alternatives

In this section, conceptual design and implementation details are developed for each of the OU-3 remedial alternatives. These remedial alternatives, with the exception of the no action alternatives, are developed to achieve the OU-3 RAOs by addressing various PRGs identified in Tables 2-1 and 2-2. Implementation details may include the locations and layouts of any required remediation equipment and support facilities; expected size and production rates of the remediation equipment; and any volume constraints, sediment quality restrictions, or significant regulatory requirements associated with a technology. Assumptions necessary to develop cost estimates are also presented. The level of detail is intended to be sufficient to estimate implementation costs and to perform other detailed evaluations of the remedial alternatives. These detailed evaluations are presented beginning in Section 5 of this report.

Figures 1-4 and 1-5 show the available OU-3 data for arsenic and mercury, respectively. Interpretations of the areal extent addressed by each of the remedial alternatives are then made to develop the conceptual design and implementation details for the marsh and river remedial alternatives.

All of the alternatives presented assume that upland sources that have caused the contamination of the OU-3 marsh and river sediments will be controlled prior to remedy implementation.

4.1 Marsh Sediments

The seven remedial alternatives identified for the OU-3 marsh range from the no action alternative (Alternative M1); to several alternatives that incorporate different combinations of technologies to varying degrees to address the marsh PRGs (Alternatives M2 through M6); to an alternative (Alternative M7) that is intended to completely remove all contaminated sediment. All of the marsh remedial alternatives except the no action alternative (Alternative M1) include removal and subsequent restoration of the highly contaminated sediments within the SPD/ADC drainage channel as an integral part of the remediation.

Beyond removal of the highly contaminated sediments within the SPD/ADC drainage channel, the PRGs that most significantly control the marsh areas and depths to be remediated are those for earthworm biomass reduction (1,050 mg/kg As and 15.5 mg/kg Hg); those identified by EPA in their June letter (160 mg/kg arsenic and 2.0 mg/kg mercury [the NJDEP severe effects level]); and those for blackworm biomass reduction (32 mg/kg arsenic and 3.6 mg/kg mercury). The most restrictive of these are 32 mg/kg arsenic and 2.0 mg/kg mercury, which therefore define the ultimate remediation goals for the marsh. For convenience in describing the marsh remedial alternatives, these most restrictive PRGs will be referred to as the “overall site PRGs” while the 1,050 mg/kg arsenic PRG will be referred to as the “hot spot PRG” and the 160 mg/kg arsenic PRG will be referred to as the “intermediate PRG.”

A summary of the marsh remedial alternatives and the RAOs and PRGs they are intended to address is presented in Table 4-1. The hot spot PRG (1,050 mg/kg arsenic) addresses potential risk to area residents (trespassers), aquatic and terrestrial invertebrate survival, terrestrial invertebrate growth, and insect-eating birds from exposure to arsenic. In addition to the above risks, the intermediate PRG (160 mg/kg arsenic) addresses potential risk to plant-eating mammals and burrowing animals from arsenic exposure. Finally, in addition to the risks addressed by the hot spot and intermediate PRGs, the overall site PRGs (32 mg/kg arsenic and 2.0 mg/kg mercury) address potential risk to aquatic invertebrate biomass reduction (arsenic, site-specific) and benthic organisms (mercury, generic). Detailed descriptions of the marsh remedial alternatives are presented in the following sections.

4.1.1 Alternative M1—No Action

The No Action alternative will include no active remediation efforts, no engineering or institutional controls, and no long-term monitoring. However, administrative activities will be required as part of EPA's long-term oversight responsibilities for the Horseshoe Road and ARC Sites. Even though no monitoring is included, natural recovery is expected with time. The administrative responsibilities are expected to involve the periodic review (every 5 years) of conditions, performed in conjunction with similar responsibilities for OU-2.

4.1.2 Alternative M2—Channel Excavation, Thin Cover, and Monitored Natural Recovery

This alternative will remove the higher contaminated sediments within the SPD/ADC drainage channel, place a thin (approximately 6 in.) aggregate/clay cover over marsh sediments that exceed EPA's intermediate PRG of 160 mg/kg arsenic, and implement MNR to address the remaining sediments that exceed the overall site PRGs of 32 mg/kg arsenic and 2.0 mg/kg mercury.

Channel excavation will be performed to a depth of 3 ft below grade throughout a 20-ft-wide corridor along the length of the SPD/ADC drainage channel and extend to include monitoring station SD38 at the mouth of the channel where it enters the Raritan River. This excavation is expected to remove the majority of contamination and be sufficiently wide and deep that channel reconstruction will prevent future erosion of sediment in the vicinity of the drainage channel. The entry of the SPD/ADC channel into the marsh is controlled by a culvert, and the upper portion of the channel is contained topographically within a shallow valley to approximately monitoring station SD35. These physical constraints and the small size and gradient of this upper portion of the channel (i.e., less than 1 ft deep, 2 to 4 ft wide and approximately 5 ft drop in elevation) limit the potential for channel incising and meandering. The potential risk of erosion in this portion of the SPD/ADC channel can be further reduced by the use of armoring. From monitoring station SD35 to the Raritan River, the SPD/ADC drainage channel crosses a tidal flat where the channel configuration is poorly defined and there is less than a 2-ft drop in elevation to normal river level. Armoring of this lower portion of the SPD/ADC drainage channel is not expected to be necessary.

The thin cover is a hybrid of both capping and enhanced natural recovery technologies that will provide erosion protection for the underlying contaminated sediments, immediate dilution of contaminant concentrations at the sediment surface, and a surficial zone of uncontaminated media for benthic habitat, without significantly raising the elevation of the marsh surface. MNR will be implemented to confirm that natural processes, primarily sedimentation via flood deposition and plant detritus buildup, are occurring at acceptable rates.

Because disturbances to the marsh and a change in the marsh topography will result from the thin cover placement, wetlands/waterfront permit equivalents and compensatory wetlands mitigation are expected to be required. Also, because moderately contaminated sediments will remain onsite, institutional and engineering controls will be needed to prevent unrestricted site access. These will include deed restrictions on future site use and the construction of a barrier fence with warning signs around the perimeter of the marsh.

A map showing the anticipated extent of Alternative M2 activities is included as Figure 4-1, and a conceptual drawing of Remedial Alternative M2 is shown in Figure 4-2. Conceptual design and implementation details for Alternative M2 are:

- A pre-design site investigation will be conducted to provide additional detail on the extent of contamination and to better define the different remediation areas. This investigation will involve a three-person crew for 4 days in the field using a portable x-ray fluorescence analyzer for arsenic concentration estimation with 10 percent of the samples submitted to an analytical laboratory to confirm the field results.

- Approximately 1,000 ft of temporary access road will be constructed across OU-2 to OU-3 and approximately 1,500 ft of temporary access road will be constructed along the eastern side of the SPD/ADC drainage, with spurs constructed to reach the other areas of the marsh for cover placement.

- Site preparation activities will include removal of the present vegetative cover over the affected area by brush cutting to avoid mixing contaminated soils with the removed vegetation. This material will then be disposed offsite as uncontaminated debris.

- A staging area will be established on the adjacent OU-2 uplands area for materials stockpiling and handling.

- Water flowing within the SPD/ADC drainage channel will be collected and pumped around active excavation areas. Also, a temporary berm, or sheet pile wall, will be constructed at the mouth of the SPD/ADC drainage channel to control tidal intrusion during excavation and channel reconstruction in the lower portion of this channel. This temporary berm will extend around the area of river sediments located at the mouth of the SPD/ADC drainage channel to allow removal of the higher contaminated sediments that occur there.

- The SPD/ADC channel excavation will be 20 ft wide and 3 ft deep throughout the approximately 1,300 ft length of the channel. An excavator will be used to remove channel sediments and to backfill with clean imported soil. Restoration of the SPD/ADC channel will involve grading the 20-ft corridor to prior site contours. An armored channel will be constructed in the upper reach from approximately Sampling Station 12 to Sampling Station SD10. From Sampling Station 12 to the Raritan River, the erosion potential is considered very small (approximately 1 ft elevation change from 4 ft at Sampling Station 12 to 3 ft at Sampling Station SD10) and will not require armored erosion protection.

- Commercially available aggregate/clay pellets such as AquaBlok® or comparable products will be used for the thin cover. The aggregate/clay pellets will be distributed using a "sling" or articulated conveyor from the temporary access roads (see Appendix F for example application methods).
- Re-establishment of marsh vegetation will be accomplished by broadcast seeding and/or planting and placement of natural fiber matting to control erosion. For the first year inspection and maintenance of the restored marsh will be conducted on a monthly basis. After the first year, inspection and maintenance will be performed in conjunction with site monitoring activities.
- The monitoring for natural recovery will involve gathering site-specific information needed to support the various lines of evidence necessary to determine the effectiveness of MNR. Five stations will be established for measurement of sediment accretion over time. Physical measurements of accretion will be supplemented with chemical analysis of vertical soil profiles for arsenic and mercury. Monitoring will be performed annually for the first 5 years, then once every 5 years for the next 25 years.
- A report of the results will be prepared after each monitoring event for EPA's consideration during their 5-year reviews of the Horseshoe Road and ARC Sites. The 5-year reviews of site conditions will be performed as part of EPA's administrative requirements for the Sites.

4.1.3 Alternative M3—Surficial Hot Spot Removal and Monitored Natural Recovery

This alternative includes the excavation and restoration of the SPD/ADC drainage channel as described in Alternative M2, the surficial (1.0 ft deep) removal and replacement of hot spot sediments (i.e., those exceeding 1,050 mg/kg arsenic), and the implementation of MNR to address the remaining sediments that exceed the overall site PRGs of 32 mg/kg arsenic and 2.0 mg/kg mercury.

Because moderately contaminated sediments will remain onsite, institutional and engineering controls will be needed to prevent unrestricted site access. These will include deed restrictions on future site use and the construction of a barrier fence with warning signs around the perimeter of the marsh.

A map showing the anticipated extent of hot spot sediment removal activities is included as Figure 4-3 and a conceptual drawing of Remedial Alternative M3 is shown in Figure 4-4. Conceptual design and implementation details for Alternative M3 are:

- Conceptual details for a pre-design site investigation and site preparation activities described for Alternative M2 will also be followed for Alternative M3.

- The conceptual design details for SPD/ADC channel excavation and restoration activities described for Alternative M2 will also be followed for Alternative M3, with the one exception being that the upper reaches of the channel will not be armored.

- An excavator will be used to remove the hot spot sediments, and to backfill with clean imported soil. For cost estimating purposes 0.5 ft of over-excavation is assumed. Also, all hot spot sediments will be classified as a RCRA hazardous waste.

- The excavated drainage channel and hot spot sediments will be dewatered onsite, then transported and disposed offsite. Onsite dewatering of the excavated sediments will be accomplished using an aboveground bermed area constructed of clean, imported soil and lined with an impermeable membrane.

- Water pumped from the excavations will be routed to temporary lined sedimentation basins or frac tanks to achieve solids removal. The decanted water will be further polished using a sand filter or a fine mesh membrane filter to comply with permit requirements prior to discharge to the Raritan River. The accumulated sediments will be included with the excavated source area soils for offsite transport and disposal.

- Re-establishment of marsh vegetation will be accomplished by broadcast seeding and/or planting and placement of natural fiber matting to control erosion. In addition, the surficial removal is likely to leave some Phragmites rhizomes in place. These rhizomes will contribute to marsh revegetation and will help stabilize remaining sediment. For the first year, inspection and maintenance of the restored marsh will be conducted on a monthly basis. After the first year, inspection and maintenance will be performed in conjunction with site monitoring activities.

- The monitoring for natural recovery will involve gathering site-specific information needed to support the various lines of evidence necessary to determine the effectiveness of MNR. Five stations will be established for measurement of sediment accretion over time. Physical measurements of accretion will be supplemented with chemical analysis of vertical soil profiles for arsenic and mercury. Monitoring will be performed annually for the first 5 years, then once every 5 years for the next 25 years.

- A report of the results will be prepared after each monitoring event for EPA's consideration during their 5-year reviews of the Horseshoe Road and ARC Sites. The 5-year reviews of site conditions will be performed as part of EPA's administrative requirements for the Sites.

4.1.4 Alternative M4—Shallow Hot Spot Removal and Thin Cover

This alternative is similar to Alternative M3 except that the depth of excavation for hot spot removal is increased from 1 ft to 2 ft and a thin cover (6 in. thick) is used instead of MNR to address the remaining sediments that exceed the overall site PRGs of 32 mg/kg arsenic and 2.0 mg/kg mercury.

Because disturbances to the marsh and a change in the marsh topography will result from the thin cover placement, wetlands/waterfront permit equivalents and compensatory wetlands mitigation are expected to be required.

A map showing the anticipated extent of Alternative M4 activities is included as Figure 4-5, and a conceptual drawing of Remedial Alternative M4 is shown in Figure 4-6. Conceptual design and implementation details for Alternative M4 are:

- Conceptual details for a pre-design site investigation, site preparation activities, and SPD/ADC channel excavation and restoration activities described for Alternative M3 will also be followed for Alternative M4.

- The hot spot sediments removal and backfilling conceptual design and implementation details described for Alternative M3 will also be followed for Alternative M4 except that the excavation and backfilling depth will be increased from 1 ft to 2 ft.

- Commercially available aggregate/clay pellets such as AquaBlok® or comparable products will be used for the thin cover. The aggregate/clay pellets will be distributed using a “sling” or articulated conveyor from the temporary access roads (see Appendix F for example application methods). These conceptual design and implementation details for thin cover are similar to those described for Alternative M2, but the area of application is larger for Alternative M4.

- Re-establishment of marsh vegetation will be accomplished by broadcast seeding and/or planting and placement of natural fiber matting to control erosion. Inspection and maintenance of the restored marsh will be conducted monthly for the first year, annually for the next 4 years, then once every 5 years for the following 25 years.

- A report of the site inspection and maintenance activities will be prepared after each site inspection for EPA’s consideration during their 5-year reviews of the Horseshoe Road and ARC Sites. The 5-year reviews of site conditions will be performed as part of EPA’s administrative requirements for the Sites.

4.1.5 Alternative M5—Extended Shallow Removal and Thin Cover

Alternative M5 is similar to Alternative M4 except the SPD/ADC channel excavation depth is shortened to coincide with the 2-ft hot spot removal depth, and shallow (1 ft deep) excavation is extended to the intermediate PRG (160 mg/kg arsenic). Alternative M5 also includes placement of backfill in the excavated area to approximately 6 in. above present grade. This increase in grade will maintain a consistent topographic profile with the thin cover placed over the remaining sediments that exceed the overall site PRGs of 32 mg/kg arsenic and 2.0 mg/kg mercury.

Because disturbances to the marsh and a change in the marsh topography will result from the thin cover placement, wetlands/waterfront permit equivalents and compensatory wetlands mitigation are expected to be required.

A map showing the anticipated extent of Alternative M5 activities is included as Figure 4-7, and a conceptual drawing of Remedial Alternative M5 is shown in Figure 4-8. Conceptual design and implementation details for Alternative M5 are:

- Conceptual details for a pre-design site investigation, site preparation activities, and thin cover placement, described for Alternative M4 will also be followed for Alternative M5.
- The conceptual details for SPD/ADC channel excavation and restoration activities will be similar to those described for prior Alternatives M2 through M4 except the depth of excavation will be 2 ft (instead of 3 ft) below grade. However, armoring of the upper reaches of the channel, as described for Alternative M2, will be included to provide protection against the potential for excessive channel erosion.
- The hot spot sediments removal and backfilling conceptual design and implementation details described for Alternative M4 will also be followed for the contaminated sediments excavated for M5.
- Re-establishment of marsh vegetation will be accomplished by broadcast seeding and/or planting and placement of natural fiber matting to control erosion. Inspection and maintenance of the restored marsh will be conducted monthly for the first year, annually for the next 4 years, then once every 5 years for the following 25 years.
- A report of the site inspection and maintenance activities will be prepared after each site inspection for EPA's consideration during their 5-year reviews of the Horseshoe Road and ARC Sites. The 5-year reviews of site conditions will be performed as part of EPA's administrative requirements for the Sites.

4.1.6 Alternative M6—Extended Deep Removal and Thin Cover

Alternative M6 involves excavating (with subsequent backfilling and restoration) the SPD/ADC drainage channel corridor to a depth of 3 ft, and the remaining areas that exceed the intermediate marsh PRG (160 mg/kg arsenic) to a depth of 2.5 ft. A thin cover will be placed over remaining areas that are less than the intermediate marsh PRG but exceed the overall site PRGs (32 mg/kg arsenic and 2.0 mg/kg mercury).

Because disturbances to the marsh and a change in the marsh topography will result from the thin cover placement, wetlands/waterfront permit equivalents and compensatory wetlands mitigation are expected to be required.

A map showing the anticipated extent of Alternative M6 activities is included as Figure 4-7, and a conceptual drawing of Remedial Alternative M6 is shown in Figure 4-9. Conceptual design and implementation details for Alternative M6 are:

- Conceptual details for a pre-design site investigation, and site preparation activities as described for prior Alternatives M2 through M5 will also be followed for Alternative M6.
- The conceptual details for SPD/ADC channel excavation and restoration activities will be similar to those described for prior Alternatives M2 through M4. These alternatives all involve excavation of the 20-ft wide corridor to a depth of 3 ft.
- The contaminated sediments removal and backfilling conceptual design and implementation details described for Alternatives M3 through M5 will also be followed for the contaminated sediments excavated for M6. However, the deeper excavation for this alternative will require higher dewatering rates requiring larger sedimentation basins or additional frac tanks. To minimize the dewatering volumes produced, the excavation activities will be performed under wet conditions, with minimal excavation dewatering performed prior to backfilling.
- Re-establishment of marsh vegetation will be accomplished by broadcast seeding and/or planting and placement of natural fiber matting to control erosion. Inspection and maintenance of the restored marsh will be conducted monthly for the first year, annually for the next 4 years, then once every 5 years for the following 25 years.
- A report of the site inspection and maintenance activities will be prepared after each site inspection for EPA's consideration during their 5-year reviews of the Horseshoe Road and ARC Sites. The 5-year reviews of site conditions will be performed as part of EPA's administrative requirements for the Sites.

4.1.7 Alternative M7—Complete Removal

This alternative involves excavating (with subsequent backfilling and restoration) the following locations: the SPD/ADC drainage channel (20 ft wide) corridor to a depth of 3 ft; the hot spot sediments (areas exceeding 1,050 mg/kg arsenic) plus those areas exceeding the intermediate PRG (160 mg/kg As) to a depth of 2.5 ft; and the remaining areas to achieve the overall site PRGs (32 mg/kg arsenic and 2.0 mg/kg mercury) to a depth of 1 ft.

Because contaminated sediments will be virtually eliminated, long-term site monitoring will not be needed under this alternative.

A map showing the anticipated extent of Alternative M7 activities is included as Figure 4-10, and a conceptual drawing of Remedial Alternative M7 is shown in Figure 4-11. Conceptual design and implementation details for Alternative M7 are:

- Conceptual details for a pre-design site investigation, and site preparation activities as described for prior Alternatives M2 through M6 will also be followed for Alternative M7.
- The conceptual details for SPD/ADC channel excavation and restoration activities will be similar to those described for prior Alternatives M2 through M4 and M6. These Alternatives all involve excavation of the 20-ft-wide corridor to a depth of 3 ft.
- The contaminated sediments removal and backfilling conceptual design and implementation details described for Alternative M6 will also be followed for the contaminated sediments excavated for M7. The deeper excavation for both of these alternatives will require higher dewatering rates than Alternatives M2 through M5, which in turn will require larger sedimentation basins or additional frac tanks. To minimize the dewatering volumes produced, the excavation activities will be performed under wet conditions, with minimal excavation dewatering performed prior to backfilling.
- Re-establishment of the marsh vegetation will be accomplished by broadcast seeding and/or planting and placement of natural fiber matting to control erosion. Inspection and maintenance of the restored marsh will be conducted monthly for the first year, and annually for the next 4 years, but no further operations and maintenance will be necessary after year 5.

4.2 River Sediments

All remedial alternatives considered for addressing river sediments are expected to be performed in conjunction with the selected remedial alternative for the OU-3 marsh sediments. All active remedial measures for river sediments (i.e., all except the no action alternative) therefore assume that a similarly active alternative will be implemented for the marsh that will allow for joint planning, permitting, and implementation. Also, a small area at the mouth of the SPD/ADC drainage channel where the highest contaminant concentrations were found (Station

SD38) is being addressed as part of the channel excavation activities incorporated into marsh Alternatives M2 through M7 and is therefore not further addressed here. The PRGs that most significantly control the areas and depths of sediments to be remediated in the river are the 194 mg/kg arsenic and 2.6 mg/kg mercury PRGs for benthic organism survival and those identified by EPA in their June and December letters (Prince 2007a,b, pers. comm.) for ambient conditions (100 mg/kg arsenic) and protection of benthic organisms (2.0 mg/kg mercury).

Six remedial alternatives have been identified for the OU-3 river sediments that include the no action alternative (Alternative R1) and other alternatives that incorporate different combinations of MNR, removal, and containment technologies to different degrees to achieve the river PRGs. Alternatives R2 through R6. All of the river remedial alternatives, except for the no action alternative, include post-remediation monitoring to document contaminant concentration changes following remediation. While the alternatives that use imported clean materials for backfill/cap material will provide close-to-pristine concentrations, it is anticipated that recontamination from the lower Raritan River will return concentrations to ambient background. A summary of the river remedial alternatives and the RAOs and PRGs that they are intended to address is presented in Table 4-2. Detailed descriptions of the river remedial alternatives are presented in the following sections.

4.2.1 Alternative R1—No Action

Similar to the no action alternative for marsh sediments, the no action alternative for river sediments will include no active remediation efforts, no engineering or institutional controls, and no long-term monitoring. However, administrative activities will be required as part of EPA's long-term oversight responsibilities for the Horseshoe Road and ARC Sites. Even though no monitoring is included, natural recovery is expected with time. Administrative responsibilities are expected to involve the periodic review (every 5 years) of conditions, performed in conjunction with similar responsibilities for OU-2.

4.2.2 Alternative R2—Monitored Natural Recovery

Alternative R2 will involve the design and implementation of a monitoring program to document the rate and effectiveness of natural processes in restoring the OU-3 Raritan River sediments to achieve the RAOs using a weight of evidence approach as described in EPA guidance (U.S. EPA 2005) and discussed in Appendix F. The primary mechanism of recovery is expected to be natural sedimentation to gradually mix with, and cover, the contaminated sediments. Conceptual design and implementation details for Alternative R2 are:

- Four monitoring stations will be established: one at a location near the mouth of the SPD/ADC drainage channel (e.g., near station RSD08), one upstream of this location (e.g., near Station RSD06), and two progressively downstream (e.g., near stations RSD10 and RSD12).

- Bathymetry surveys and core sampling will be performed on an annual basis for 4 years to document changes in sediment surface elevations and for depth profile analysis of arsenic and mercury.

- A report of the results will be prepared after each monitoring event for EPA's consideration during their 5-year review of the Horseshoe Road and ARC Sites. The 5-year reviews of conditions will be performed as part of EPA's administrative requirements for the Sites.

4.2.3 Alternative R3—Shallow Dredge and Thin Cap

This alternative involves the shallow dredge removal of sediments (approximately 1 ft deep) that exceed the 194 mg/kg arsenic and 2.6 mg/kg mercury PRGs for benthic organism survival, subsequent backfilling of the dredged area, and the placement of a thin cap (approximately 6 in. thick) over the remaining contaminated river sediments (as bounded by Stations RSD04, RSD14, and the shoreline, as well as a small area around Location 8 in the embayment) to achieve the ambient PRGs for this portion of the Raritan River.

Figure 1-3 shows that the OU-3 river sediments are generally less than 3 ft below the water surface. Because of this shallow depth, a thin layer cap (approximately 6-in. thick) will be constructed. The thin layer cap is a hybrid of both capping and enhanced natural recovery technologies that will provide immediate dilution of contaminant concentrations at the sediment surface, and a layer of clean substrate to reduce the exposure of ecological receptors to the underlying contaminated sediments.

A map showing the anticipated extent of Alternative R3 activities is included as Figure 4-12, and a conceptual drawing of Remedial Alternative R3 is shown in Figure 4-13. Conceptual design and implementation details for Alternative R3 are:

- The dredging, backfilling, and thin cap placement will be accomplished from a barge. Staging of materials and barge loading will occur at a nearby offsite location. Because of the shallow water depths, barge movement will be limited by tidal conditions resulting in relatively low dredging, backfilling, and thin cap application rates.

- Dredging will be performed by crane with a clam shell bucket while backfilling of the dredged area and thin cap placement will be accomplished by either hydraulically washing clean sand from a barge or by distributing the sand using an articulating conveyor.

- Silt curtains will be deployed around the active area to prevent sediment transport and to control potential water quality impacts to the Raritan River.

- Dredged materials will be placed on a separate barge for dewatering and subsequent transport to the staging area. From there the remaining solids will be transferred to trucks for transport and offsite disposal at an appropriate landfill.

- Decanted water from the dredged materials will be allowed to settle, then filtered to remove suspended solids before being discharged back to the river.

- Clean sand from an offsite location will be used to backfill the dredged area and for thin capping.

- Bathymetry surveys and core sampling will be performed before and during performance of the remedial activities to confirm dredge depth and backfill and thin cap thicknesses, and to document depth profile concentrations of arsenic and mercury. A similar bathymetric survey and core sampling program will be implemented to monitor sediment stability and recovery following the completion of remedial activities. Monitoring will be performed on an annual basis for the first 5 years, then once every 5 years for the next 25 years.

- A report of the results will be prepared after each monitoring event for EPA's consideration during their 5-year reviews of the Horseshoe Road and ARC Sites. The 5-year reviews of site conditions will be performed as part of EPA's administrative requirements for the Sites.

4.2.4 Alternative R4—Extended Shallow Dredge

This alternative is similar to Alternative R3 except, instead of a thin cap, the shallow dredging is extended to cover the entire OU-3 area that exceeds the ambient river PRGs. This area is bounded by Stations RSD04, RSD14, and the shoreline and includes a small area around Station 8 in the embayment. As with Alternative R3, the target thickness of the shallow dredging will be 1 ft and the dredged area will be backfilled with clean imported materials.

A map showing the anticipated extent of Alternative R4 activities is included as Figure 4-14, and a conceptual drawing of Remedial Alternative R4 is shown in Figure 4-15. Dredging and backfilling will be accomplished by barge as described for Alternative R3. Conceptual design and implementation details for Alternative R4 are:

- Staging of materials and barge loading will occur at a nearby offsite location. Because of the shallow water depths, barge movement will be limited by tidal conditions resulting in relatively low dredging and backfilling rates.

- Silt curtains will be deployed around the active area to prevent sediment transport and to control potential water quality impacts to the Raritan River.

- Dredged materials will be placed in a separate barge for dewatering and subsequent transport to the staging area. From there the remaining solids will be transferred to trucks for transport and offsite disposal at an appropriate landfill.

- Decanted water from the dredged materials will be allowed to settle, then filtered to remove suspended solids before being discharged back to the river.

- Clean sand from an offsite location will be used to backfill the dredged area.

- Bathymetry surveys and core sampling will be performed before and during performance of the remedial activities to confirm dredge depth and backfill thickness, and to document depth profile concentrations of arsenic and mercury. A similar bathymetric survey and core sampling program will be implemented to monitor sediment stability and recovery following the completion of remedial activities. Monitoring will be performed once every 5 years for 30 years.

- A report of the results will be prepared after each monitoring event for EPA's consideration during their 5-year reviews of the Horseshoe Road and ARC Sites. The 5-year reviews of conditions will be performed as part of EPA's administrative requirements for the Sites.

4.2.5 Alternative R5—Deep Dredge and Monitored Natural Recovery

This alternative is similar to Alternative R4 except the depth of dredging is extended to a target depth of 3.5 ft and natural sedimentation will be relied upon to return the dredged area to ambient conditions. A monitoring program will be implemented to document the progress of the natural recovery process.

A map showing the anticipated extent of Alternative R5 dredging activities is included as Figure 4-14, and a conceptual drawing of Remedial Alternative R5 is shown in Figure 4-16. All dredging operations will be conducted from a barge. Conceptual design and implementation details for Alternative R5 are:

- The conceptual design and implementation details described for dredging operations under Alternative R4 will also be followed for Alternative R5, except the dredge depth and the resulting dredge volume will be larger.

- Bathymetry surveys and core sampling will be performed before and during performance of the remedial activities to confirm dredge depth, and to document depth profile concentrations of arsenic and mercury. A similar bathymetric survey and core sampling program will be implemented to monitor sedimentation rates and to confirm natural recovery following the completion of remedial activities. Monitoring will be performed on an annual basis for the first 5 years, then once every 5 years for the next 25 years.

- A report of the results will be prepared after each monitoring event for EPA's consideration during their 5-year reviews of the Horseshoe Road and ARC Sites. The 5-year reviews of conditions will be performed as part of EPA's administrative requirements for the Sites.

4.2.6 Alternative R6—Deep Dredge and Cover

This alternative is similar to Alternative R5 except the dredged area will be backfilled instead of relying on natural sedimentation for recovery. As with Alternative R5 the target thickness of the deep dredging will be 3.5 ft and, similar to Alternatives R3 and R4, the dredged area will be backfilled with clean imported materials. Because of the extent of removal and backfilling performed under Alternative R6, continued site monitoring beyond the first 5-year review is assumed to be unnecessary.

A map showing the anticipated extent of Alternative R6 dredging and backfilling activities is included as Figure 4-14 and a conceptual drawing of Remedial Alternative R6 is shown in Figure 4-17. All dredging and backfilling operations will be conducted from a barge. Conceptual design and implementation details for Alternative R6 are:

- The conceptual design and implementation details described for dredging and backfilling operations under Alternative R4, will also be followed for Alternative R6, except the dredge depth and the resulting dredge and backfill volumes are larger.
- Bathymetry surveys and core sampling will be performed before and during performance of the remedial activities to confirm dredge depth and backfill thickness, and to document depth profile concentrations of arsenic and mercury. A similar bathymetric survey and core sampling program will be performed once, 5 years following the completion of remedial activities to confirm that sediment recontamination above ambient conditions is not occurring. The results of this monitoring event will be provided to EPA for their consideration in the first 5-year review of the Horseshoe Road and ARC Sites. Assuming that no significant recontamination is indicated no further monitoring or reporting activities are anticipated.

5 Individual Analysis of Alternatives

This section presents a detailed evaluation of each remedial alternative for the OU-3 marsh and river sediments, in accordance with the NCP and Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) guidance. Each of the remedial alternatives is evaluated against two “threshold” criteria and five “balancing” criteria. The threshold criteria must be met by a particular alternative for it to be eligible for selection as a remedial action, while the balancing criteria weigh the trade-offs between alternatives. In addition, there are two “modifying” criteria that are addressed by EPA following the completion of the feasibility study as part of the final remedy selection. The nine evaluation criteria are listed in Table 5-1 and described below.

Overall Protection of Human Health and the Environment—Protectiveness of human health and the environment is the primary requirement that remedial actions must meet under CERCLA. A remedy is protective if it adequately eliminates, reduces, or controls all current and potential risks posed by the site through each exposure pathway. The assessment against this criterion describes how the alternative achieves and maintains protection of human health and the environment.

Compliance with ARARs—ARARs are cleanup standards, standards of control, and other substantive environmental statutes or regulations which are either “applicable” or “relevant and appropriate” to the CERCLA cleanup action. Applicable requirements address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site. Relevant and appropriate requirements are those that, while not applicable, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to environmental or technical factors at that site. The assessment against this criterion describes how the alternative complies with ARARs or presents the rationale for waiving an ARAR. The following potential ARARs are evaluated for compliance:

- **Chemical-specific ARARs:** Chemical-specific ARARs include federal and state standards applicable to a particular contaminant and media. These may include drinking water, air, and surface water standards.

- **Location-specific ARARs:** Location-specific ARARs require protection of particular unique resources, including the floodplain, fish and wildlife, streambed, cultural and historic resources, threatened and endangered species, and wetlands.

- **Action-specific ARARs:** Action-specific ARARs include regulations addressing the particular activities to be implemented. These may include notification and permitting requirements for handling, transportation, and storage of wastes; control of stormwater runoff, wastewater treatment and discharge; and dredge and fill activities.

- **To Be Considered:** "To Be Considered" requirements include occupational safety and health regulations, public water supply requirements for modification of any public water supply line or sewer line, water rights, etc.

For each alternative, the evaluation of compliance with ARARs will address whether the ARARs can be met and, if not, whether a waiver is appropriate (U.S. EPA 1988). The specific grounds upon which ARARs may be waived are specified in CERCLA and the NCP.

Long-term Effectiveness and Permanence—The long-term effectiveness and permanence criterion primarily addresses the risk remaining at the site after the remedial alternative has been implemented and the RAOs have been achieved. This analysis includes consideration of the degree of threat posed by hazardous substances remaining at the site and the adequacy and reliability of any controls (e.g., engineering or institutional controls) used to manage the hazardous substances remaining at the site. It also addresses the type, degree, and duration of post-closure care required, and the potential need for replacement of components of the remedy.

Reduction of Toxicity, Mobility, or Volume through Treatment—This criterion addresses the statutory preference for remedies that employ treatment as a principal element. The assessment against this criterion evaluates the anticipated performance of the specific treatment technologies an alternative may employ. The criterion is specific to evaluating only how treatment reduces toxicity, mobility, or volume of contaminants, and does not address containment actions such as capping.

Short-term Effectiveness—This criterion addresses short-term impacts during implementation of the alternatives. The assessment against this criterion examines the effectiveness of alternatives in protecting human health and the environment (i.e., minimizing any risks associated with an alternative) during the construction and implementation of a remedy, until the response objectives have been met. Examples of short-term effectiveness concerns include increased traffic accident risks on local roads related to remediation, increases in turbidity and relative habitat disruption as a result of construction, and the length of time until the RAOs are attained.

Implementability—This criterion refers to the technical and administrative feasibility of implementing an alternative and the availability of various materials and services required during its implementation. Technical feasibility considerations include the ability to construct the alternative, the reliability of a technology to meet specified process efficiencies or performance goals, and the ease of undertaking future remedial actions that may be required. Administrative feasibility involves the degree of difficulty anticipated to coordinate with other offices and agencies, and to obtain permits, access agreements, or rights-of-way and easements required to implement the remedial alternative.

Cost—Cost estimates for each remedial alternative include direct and indirect capital costs, annual operation and maintenance costs, and present worth costs. Direct capital costs may include construction costs, land and site development, building and services costs, relocation expenses, and disposal costs. Indirect capital costs could include engineering expenses, licensing or permitting costs, start-up and shakedown costs, and contingency allowances. Contingency allowances include funds to cover costs resulting from unforeseen circumstances, such as adverse weather conditions. Operation and maintenance costs are post-construction costs necessary to ensure the continued effectiveness of a remedial action, and may include monitoring, operating labor costs, maintenance materials and energy costs, disposal of residue costs, purchased services, administrative costs, insurance and licensing costs, taxes, and costs of periodic site reviews.

A present worth analysis is used to evaluate expenditures that occur over different time periods by discounting all future costs to the current year. The net present worth calculated for each alternative is based on using a 7 percent discount rate over a 30-year period. Cost estimates for each of the remedial alternatives were developed in accordance with the latest *Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (U.S. EPA 2000). These detailed cost estimates are presented in Appendix E.

State Acceptance—State acceptance evaluates the technical and administrative issues and concerns of the state, and is assessed based on comments in project meetings and correspondence and comments on project documents, to the extent possible. A final evaluation of state acceptance will be conducted by EPA and therefore is not evaluated further in this feasibility study.

Community Acceptance—This assessment evaluates the concerns the public may have regarding each of the alternatives. A final evaluation of community acceptance will be addressed by EPA after presentation of their proposed plan to the public, and therefore is not evaluated further in this feasibility study.

5.1 Evaluation of Marsh Alternatives

The results of the detailed evaluations of remedial alternatives for the marsh are presented in the following sections. Detailed evaluations are presented in tabular form and important aspects of the evaluations, significant uncertainties, or clarification of issues of interest are discussed. Comparative analysis of all of the alternatives with respect to each of the evaluation criteria is presented in Section 6.

5.1.1 Alternative M1—No Action

The detailed evaluation of Alternative M1 is presented in Table 5-2. This alternative includes no active remedial measures; therefore, current risks to human health and the environment, discussed in Sections 1.5 and 1.6, will remain. For human health, these risks are a noncarcinogenic hazard index > 1.0, for area residents (trespassers) who might come into direct contact with arsenic-contaminated sediment in the marsh and the Raritan River during recreational activities.

Ecological risks include a potential for adverse effects on growth (i.e., biomass reduction) in aquatic and terrestrial invertebrates, and the potential for adverse effects on individual insect-eating birds and plant-eating mammals in the areas of the marsh, where contaminant concentrations (primarily arsenic, mercury, and PCBs) are highest.

5.1.2 Alternative M2—Channel Excavation, Thin Cover, and Monitored Natural Recovery

Detailed evaluation of Alternative M2 is presented in Table 5-3. The SPD/ADC channel excavation and restoration will remove the most mobile contaminated sediments in the marsh, and the placement of a thin cover over the remaining hot spot and moderately contaminated sediments (i.e., those exceeding 160 mg/kg arsenic) will further reduce the potential for human and ecological exposure. MNR is relied upon both in the thin capped areas and the remaining uncapped areas to gradually achieve the overall site PRGs. The progress of the natural recovery will be monitored and provide the data necessary to make future decisions on the need for further actions.

Significant uncertainties concerning Alternative M2 include the potential for erosion of remaining contaminated sediments during flood events and the rate of natural recovery.

A preliminary evaluation of the SPD/ADC drainage channel and Raritan River scour velocities at OU-3 for 100-year frequency flood flows was performed by Exponent (Appendix C) to address the potential for erosion. While site-specific information was limited, the analysis indicated that the potential for erosion of marsh sediments is low. Vegetative cover and cohesive soils, if present, are factors that would further reduce the potential for erosion. Also, the design and construction of an armored channel for the restored SPD/ADC drainage channel is included in the conceptual design of this alternative to prevent incising and excessive meandering from occurring.

The rate of natural recovery at OU-3 will largely be dependent on sediment deposition during flooding and also on the buildup of detritus from the marsh vegetation. The monitoring program included as a fundamental element in this remedial alternative is expected to provide the information necessary to estimate the rate of natural recovery, and 5-year reviews by EPA will provide the opportunity to assess whether additional remedial measures are needed.

5.1.3 Alternative M3—Surficial Hot Spot Removal and Monitored Natural Recovery

The detailed evaluation of Alternative M3 is presented in Table 5-4. The SPD/ADC channel excavation and restoration will remove the most mobile contaminated sediments in the marsh, and the surficial removal of hot spot sediments and subsequent backfilling actions will further reduce potential human and ecological exposure within those excavated areas. MNR is relied upon both in the remaining uncapped areas to gradually achieve the overall site PRGs. The progress of the natural recovery will be monitored and provide the data necessary to make future decisions on the need for further actions.

Significant uncertainties concerning Alternative M3 include the actual extent of soils that exceed hot spot concentrations, the potential for erosion of remaining contaminated sediments during flood events, and the rate of natural recovery.

The extent of hot spot soils as shown on Figure 4-3 is estimated to be approximately 2.2 acres. However, the large distance between sampling stations and the lack of surveyed location coordinates for many of these stations makes this estimate highly uncertain. This uncertainty greatly impacts the remedial cost estimate for this alternative because of the high unit costs anticipated for offsite disposal of the hot spot sediments as RCRA hazardous waste. The conceptual design for Alternative M3 includes a pre-design study for better delineation of hot spot marsh sediments to reduce this uncertainty. The risks associated with the uncertainties for erosion from flooding and the rate of natural recovery were previously discussed in Section 5.1.2.

5.1.4 Alternative M4—Shallow Hot Spot Removal and Thin Cover

Detailed evaluation of Alternative M4 is presented in Table 5-5. This alternative removes all of the hot spot sediments through excavation and restoration of the SPD/ADC channel and hot spot sediments thereby reducing potential human and ecological exposures to the higher contaminated sediments and greatly reducing the potential for contaminant transport. Placement of a thin cover over the remaining less contaminated sediments along with the implementation of deed restrictions and perimeter fencing to restrict access will further reduce the potential for human and ecological exposure.

As with all alternatives that involve hot spot sediment removal, the uncertainty concerning the extent of these sediments greatly impacts the cost of remediation. A pre-design study is included in the conceptual design to reduce this uncertainty. Another area of uncertainty is the acceptability by permitting agencies of the change in topographic elevation that will occur because of the thin cover placement. The conceptual design for this alternative includes acquisition of wetlands property to mitigate the partial loss of the OU-3 marsh caused by this cover.

5.1.5 Alternative M5—Extended Shallow Removal and Thin Cover

The detailed evaluation of Alternative M5 is presented in Table 5-6. This alternative removes virtually all of the hot spot and moderately contaminated sediments through the excavation and restoration of the SPD/ADC channel and also the excavation and backfilling of contaminated sediments in excess of 160 mg/kg arsenic. This reduces or eliminates potential human and ecological exposures to the higher and moderately contaminated sediments and greatly reduces the potential for contaminant transport. Placement of a thin cover over the remaining less contaminated sediments along with the implementation of deed restrictions and perimeter fencing to restrict access will further reduce the potential for human and ecological exposure.

As with all alternatives that involve hot spot sediment removal, the uncertainty concerning the extent of these sediments greatly impacts the cost of remediation. A pre-design study is included in the conceptual design to reduce this uncertainty. Also, the conceptual design for this alternative includes the acquisition of wetlands property to mitigate the partial loss of the OU-3 marsh because of the change in topographic elevation caused by thin cover placement and backfill.

5.1.6 Alternative M6—Extended Deep Removal and Thin Cover

The detailed evaluation of Alternative M6 is presented in Table 5-7. This alternative extends the depth of removal within the hot spot and moderately contaminated areas to provide even greater assurance against the potential exposure by human or ecological receptors and the potential erosion of residual contaminated sediments. Placement of a thin cover over the remaining less contaminated sediments along with the implementation of deed restrictions and perimeter fencing to restrict access further reduces the potential for human and ecological exposure.

In addition to concerns about the extent of hot spot sediments, there is the uncertainty about potential dewatering rates in the deeper excavations that will occur with the increased removal depths for this alternative. This uncertainty is dependent on the size of the open excavation area as well as sediment permeability and the depth to groundwater. This is expected to be addressed during remedial design.

5.1.7 Alternative M7—Complete Removal

The detailed evaluation of Alternative M7 is presented in Table 5-8. Expanding the excavation to the depths and full extent outlined in EPA's December letter (Prince 2007b, pers. comm.) will reduce human health and ecological risks to acceptable levels, and eliminate concerns for potential erosion of residual contaminated sediments. No residual contaminants of concern for human health or ecological exposure will remain; therefore, no long-term monitoring or site review activities will be necessary. Also, revegetation of the marsh after completing the removal and backfilling activities could present an opportunity to establish a more desirable plant community than the existing *Phragmites*.

5.2 Evaluation of River Alternatives

The results of the detailed evaluations of remedial alternatives for the river are presented in the following sections. The detailed evaluations are presented in tabular form and important aspects of the evaluations, significant uncertainties, or clarification of issues of interest are discussed. Comparative analysis of all of the alternatives with respect to each of the evaluation criteria is presented in Chapter 6.

5.2.1 Alternative R1—No Action

The detailed evaluation of Alternative R1 is presented in Table 5-9. This alternative includes no active remedial measures; therefore, current risks to human health and to benthic organisms will remain. However, potential risk to trespassers (where arsenic concentrations exceed 2,000 mg/kg) has been identified only at the mouth of the SPD/ADC drainage and this area is included with source area sediments under the marsh portion of OU-3. Therefore, the potential for human health risk will remain only if no action is conducted for both the marsh and the river sediments.

The PRGs for protection of benthic organisms are 194 mg/kg arsenic and 2.6 mg/kg mercury. These risks will not be directly or immediately addressed by the no action alternative and RAO5 will not be achieved in this area.

Under Alternative R1, natural recovery will gradually occur as contributing sources of contaminants (i.e., the SPD/ADC drainage) are remediated and as Raritan River sediment deposition occurs. However because no monitoring will be performed, the rate of this recovery will not be known.

5.2.2 Alternative R2—Monitored Natural Recovery

Detailed evaluation of Alternative R2 is presented in Table 5-10. This alternative relies on natural processes to reduce the potential for exposure by human and ecological receptors. The short-term risks are the same as for the no action alternative (Alternative R1) except that monitoring will be performed to estimate the rate of recovery and to confirm its progress.

The rate of natural recovery will largely be dependent on sediment deposition during flooding. The monitoring program included as a fundamental element in this remedial alternative is expected to provide the information necessary to estimate the rate of natural recovery, and 5-year reviews by EPA will provide the opportunity to assess the need for additional remedial measures. MNR is a recognized remedial approach for addressing contaminated sediments (U.S. EPA 2005) and this type of phased approach is consistent with EPA guidance on managing contaminated sediment risks (U.S. EPA 2002).

5.2.3 Alternative R3—Shallow Dredge and Thin Cap

Detailed evaluation of Alternative R3 is presented in Table 5-11. This alternative reduces the potential for exposure by human and ecological receptors by partial removal of the higher contaminated sediments and by creating a surface layer of clean sediments (by backfilling and thin cap placement) over the residual contaminated sediments. Disturbance to the sediments and potential effects to Raritan River water quality are minimized by the use of silt curtains and by the backfilling/capping application method used (articulating conveyor from a barge). However, increasing the bottom elevation of a portion of the Raritan River, even by the minimal thickness of the proposed thin layer, may not be acceptable to the agencies responsible for permitting these activities (primarily the Corps).

Another significant uncertainty concerning Alternative R3 is the potential for erosion of the thin layer cap by scour velocities of Raritan River flows; however the erosion potential is expected to be low. A preliminary evaluation of Raritan River scour velocities at OU-3 for 100-year frequency flood flows was performed by Exponent (Appendix C) to address the potential for erosion. While site-specific information was limited, the analysis indicated that the potential for erosion of river sediments is low.

5.2.4 Alternative R4—Extended Shallow Dredge

Detailed evaluation of Alternative R4 is presented in Table 5-12. This alternative reduces human health and ecological risks to acceptable levels by extending the shallow dredging to reach ambient Raritan River conditions and by creating a surface layer of clean sediments by backfilling over the residual contaminated sediments.

As with all alternatives that include dredging, a significant uncertainty for this alternative is the degree of difficulty that will be encountered in deploying barge-based equipment in this shallow, tidally-affected area. The costs for implementation will be directly affected by dredging and backfilling production rates. Another uncertainty is the depth of dredging and backfilling required to protect underlying contaminated sediments from potential scour by Raritan River flows. Preliminary analysis of Raritan River scour velocities for a 100-year flood event indicate that the potential for erosion of the bottom sediments is low (see Appendix C). Consideration of these uncertainties is expected to be addressed in more detail during remedial design.

5.2.5 Alternative R5—Deep Dredge and Monitored Natural Recovery

Detailed evaluation of Alternative R5 is presented in Table 5-13. This alternative reduces human health and ecological risks to acceptable levels by removal of all contaminated sediments above the maximum river reference value for arsenic and the NJDEP sediment screening value for mercury (100 mg/kg arsenic and 2.0 mg/kg mercury, respectively). No backfilling is included, this alternative relies instead on natural sedimentation to return the area to ambient conditions.

As with all alternatives that include dredging, a significant uncertainty for this alternative is the degree of difficulty that will be encountered in deploying barge-based equipment in this shallow, tidally-affected area.

Both the volume dredged and the production rates for dredging will have a direct effect on the cost of implementation. These uncertainties are expected to be further addressed during remedial design.

5.2.6 Alternative R6—Deep Dredge and Cover

Detailed evaluation of Alternative R6 is presented in Table 5-14. This alternative is similar to Alternative R5 in the extent of dredging but incorporates backfilling with clean imported materials to return the area to current bottom elevations and contours. This reduces human health and ecological risks to acceptable levels by removal of all contaminated sediments above the maximum river reference value for arsenic and the NJDEP sediment screening value for mercury (100 mg/kg arsenic and 2.0 mg/kg mercury, respectively).

Both the volume dredged and the production rates for dredging and backfilling will have a direct effect on the cost of implementation.

6 Comparative Analysis Between Alternatives

This section presents the final part of the alternatives evaluation process by incorporating the risks, implementation methods, costs, and PRG options developed in the previous sections of the feasibility study. This section provides a comparative analysis among the remedial alternatives, to assess the relative performance of each alternative with respect to the seven CERCLA criteria: overall protection of human health and the environment; compliance with ARARs; long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; short-term effectiveness; implementability (technical and administrative feasibility); and cost.

6.1 Marsh

The following sections present a comparative analysis among remedial alternatives for the marsh with respect to the seven CERCLA criteria.

6.1.1 Overall Protection of Human Health and the Environment

All of the marsh alternatives (except the no action alternative, Alternative M1) achieve RAO1 (reduce human health risks to acceptable levels) and RAO3 (minimize contaminant migration through surface water runoff or erosion) by removing potential hot spot sediments. RAO2 (to reduce ecological risks to acceptable levels) is achieved by Alternative M2 through partial removal, containment, and natural recovery; by Alternative M3 through partial removal and natural recovery; and by Alternatives M4, M5, and M6 through progressively greater volumes of removal and containment. Alternative M7 achieves all RAOs by complete removal of all contaminated marsh sediments. Alternative M1 is not protective of human health or the environment but is required in the evaluation process to represent current conditions for comparison purposes.

6.1.2 Compliance with ARARs

All of the chemical-specific, action-specific, and location-specific ARARs of concern associated with the implementation of each of the marsh alternatives (M1 through M7) can reasonably be expected to achieve compliance through proper planning and implementation. Alternatives M2, M4, M5, and M6 may have difficulty meeting action-specific ARARs associated with negative effects to wetlands because of changes in elevation as a result of thin cover placement. There are no other distinguishing positive or negative aspects associated with this evaluation criterion to differentiate between alternatives.

6.1.3 Long-term Effectiveness and Permanence

All marsh alternatives except Alternative M1 (the no action alternative) permanently achieve RAO1, RAO2, and RAO3 but vary in the time frames required to achieve these RAOs and the magnitude of residual risk. Alternatives M2 and M3 will require the longest time to achieve the remedial objectives because of their reliance on natural recovery. Alternative M2 through M6 leave progressively smaller amounts of contaminants in place. Alternative M7 will achieve the RAOs upon completion of the excavation and backfilling activities.

Alternatives M2 and M3 will require monitoring to determine natural recovery rates, and evaluation to confirm the acceptability of those rates. The results of this monitoring are expected within a short (5-year) time frame and are expected to be adequate and reliable. Periodic site inspections and cover maintenance will be necessary for Alternatives M2 through M6 to reduce the potential for future exposure to the covered residual contaminated sediments. The reliability of continuing long-term site monitoring and maintenance for these alternatives could decrease in the long term if site responsibilities are unclear or if funding levels diminish. However, these control measures are considered adequate because of the low residual risks and the CERCLA administrative procedures that are in place to track sites with residual contaminants. Alternative M7 will leave little residual contamination and will not require long-term maintenance or monitoring.

6.1.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Principal threat wastes do not exist within the OU-3 area and no treatment of excavated marsh sediments is anticipated for any of the remedial alternatives. Therefore, there will be no reduction of toxicity, mobility, or volume through treatment achieved by any of the marsh remedial alternatives.

6.1.5 Short-term Effectiveness

Alternatives M2 through M7 will have short-term, onsite impacts during implementation that may include temporary alteration of hydrological function of stream channels, short-term impairment of stream benthic and aquatic communities, complete removal of marsh vegetation, and loss of wildlife habitat. Alternative M3 will have the least amount of disruption, limited primarily to the hot spot area. Alternative M2 will be more disruptive than Alternative M3 but slightly less disruptive than Alternatives M4, M5, M6, and M7 because excavation and cover placement extends over a smaller portion of the OU-3 marsh. The impacts caused by Alternatives M5, M6, and M7 will be similar because of similar areas of site disturbance but progressively more severe because of the deeper excavation depths and areal extents, and correspondingly larger volumes removed. Site controls such as security fencing, drainage diversion, sedimentation basins, and silt fencing will minimize potential impacts to the surrounding environment and the community. Following completion of the site work, recovery from onsite impacts for Alternatives M2 through M7 is expected to be rapid, and the marsh should attain full ecological function within 2 years.

Workers implementing Alternatives M2 through M7 will be exposed to contaminated sediments and water, and also to physical hazards associated with heavy equipment construction activities. Adherence to an appropriate health and safety plan will limit these risks.

No remedial actions are associated with Alternative M1, so there would be no adverse impacts to the environment. For the remaining alternatives (M2 through M7), environmental impacts will be expected for areas of the channel and marsh where excavation and capping occur, as well as other areas affected by movement of machinery needed to perform remedial actions. The time required to achieve the RAOs is unknown for Alternative M1, while the RAOs would be attained upon completion of construction activities for Alternative M4 (estimated at less than 2 months), Alternatives M5 (estimated at less than 3 months), and Alternatives M6 and M7 (estimated at less than 5 months). Similarly for Alternatives M2 and M3, the RAOs will be substantially achieved upon completion of excavation and backfill/cover activities (estimated at less than 2 months), but complete attainment of the site RAOs will depend on the rate of natural recovery and may take years.

6.1.6 Implementability

Alternative M1 is the easiest to implement because there are no activities that require administrative coordination or approval and there are no activities that rely on equipment, materials, or services. The remaining six marsh alternatives (M2 through M7) are implementable. Although the removal in the marsh and tidelands are challenging tasks, the equipment, materials, and skills needed to perform these actions are readily available. Application of the thin cover in Alternatives M2, M4, M5, and M6 could be performed using several alternative methods and presents no significant implementation problems. Similar removal and cover actions have been implemented successfully at other sites with similar conditions.

6.1.7 Cost

The cost of implementation for the OU-3 marsh alternatives rises in order from the least cost Alternative M1 at an estimated total present value of $100,000, to the highest cost, Alternative M7 at an estimated total present value of $20,700,000 (see Table 6-1). There is considerable uncertainty in these estimated costs because of uncertainty in the extent of hot spot sediments (defined as >1,050 mg/kg arsenic) and the high unit cost for disposal assuming classification as a RCRA hazardous waste. The uncertainty in estimated costs affects Alternative M2 the least because the removal volume for the SPD/ADC drainage channel corridor is defined and the additional hot spot sediments are contained rather than removed for offsite disposal.

6.2 River

The following sections present a comparative analysis among the river remedial alternatives with respect to the seven CERCLA criteria.

6.2.1 Overall Protection of Human Health and the Environment

Because the PRG for protection of human health (2,000 mg/kg arsenic) is addressed as part of source removal activities identified in remedial alternatives M2 through M7 for the marsh, RAO4 (reduction of the potential for human health risks) will be an issue in the river portion of OU-3 only if Alternative M1 (no action) is selected for the marsh. Even though Alternative R1, the no action alternative, is the least protective of human health and the environment, it will nonetheless achieve RAO4 if any of the marsh alternatives M2 through M5 are implemented. Alternative R1 does not otherwise achieve overall site PRGs provided by EPA (100 mg/kg arsenic and 2.0 mg/kg mercury) but is required in the evaluation process to represent current conditions for comparison purposes. Alternative R2 achieves the river RAOs through natural recovery while this is accomplished by Alternatives R3 through R6 through progressively greater volumes of removal and containment. Alternative R6 achieves all RAOs by complete removal of all contaminated OU-3 river sediments to the extent requested by EPA.

6.2.2 Compliance with ARARs

As discussed in the sections regarding ARARs in Section 5, there are chemical-specific, action-specific, and location-specific ARARs of concern associated with the implementation of each of the alternatives, but all of them can reasonably be expected to achieve compliance through proper planning and implementation. The placement of a thin cap for Alternative R3 will have the greatest difficulty in complying with action-specific ARARs because of the slight increase of the river bed elevations resulting from cap placement. There are no other distinguishing positive or negative aspects associated with this evaluation criterion to differentiate between alternatives.

6.2.3 Long-term Effectiveness and Permanence

Alternatives R1 and R2 will require the longest time to achieve the RAOs and will leave the largest mass of contaminants in place. Alternatives R3 and R4 achieve the RAOs in a time frame similar to one another, but vary by the magnitude of residual risk. Alternative R4 leaves less residual contaminant mass in place than Alternative R3 but more than Alternatives R5 and R6. Alternatives R5 and R6 both lower the residual risks to ambient conditions by effectively removing all contaminated sediments..

Alternative R2 will require monitoring to determine natural recovery rates and evaluation to confirm the acceptability of those rates. The results of this monitoring are expected within a short (5-year) time frame and are expected to be adequate and reliable. Periodic site inspections and cap maintenance will be necessary for Alternatives R3 and R4 to reduce the potential for future exposure to the covered residual contaminated sediments. The reliability of continuing long-term site monitoring and maintenance for these alternatives could decrease in the long term if site responsibilities are unclear or if funding levels diminish. However, these control measures are considered adequate because of the low residual risks and the CERCLA administrative procedures that are in place to track sites with residual contaminants.

6.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Treatment of removed sediments is not expected under any of the river remedial alternatives; therefore, no reduction of toxicity, mobility, or volume will occur.

6.2.5 Short-term Effectiveness

Alternatives R1 and R2 are the least intrusive alternatives, and would have very low to no short-term effects on the local ecology or surrounding communities, or to onsite workers. Alternatives R3, R4, R5, and R6 will all have short-term, onsite impacts during implementation that may include temporary alteration of hydrological function of this portion of the Raritan River, short-term impairment of river benthic and aquatic communities, and effects on Raritan River water quality. Alternatives R3, R4, R5, and R6 will have progressively greater disruption corresponding to progressively greater dredging areas and depths and also time of disturbance. Site controls such as silt curtains and treatment of dredged sediment decanted water will minimize potential impacts to the surrounding environment and the community.

Onsite operations are expected to be completed within 1 month for both Alternatives R3 and R4, within 2 months for Alternative R5, and within 3 months for Alternative R6. Following completion of the site work, recovery from onsite impacts for Alternatives R3 through R5 is expected to be rapid, and OU-3 river sediments should achieve a functioning benthic community within 2 years. However the time required to complete administrative requirements including planning, pre-design investigations, remedial design plan and specifications development, permitting, and remedial contractor selection and contracting will be significant (estimated at 3 to 8 years) for Alternatives R3 through R6. During this pre-implementation period, current risks to invertebrates will continue. Alternative R2 (MNR) can be implemented (i.e., the monitoring component) in a much shorter time (estimated at 1 to 2 years) and its effectiveness evaluated by the time onsite activities could begin on Alternatives R3, R4, R5, or R6.

Workers implementing Alternatives R3, R4, R5 and R6 will be exposed to contaminated sediments and water, and also to physical hazards associated with heavy equipment construction activities. Adherence to an appropriate health and safety plan will limit these risks.

6.2.6 Implementability

Alternative R1 is the easiest to implement because there are no activities that require administrative coordination or approval and there are no activities that rely on equipment, materials, or services. Alternative R2 is significantly easier to implement than the remaining three river alternatives (R3 through R6) because there are no construction activities performed in the Raritan River. The construction activities that are included in Alternatives R3 through R6 will all require significant administrative effort to obtain permits and to coordinate with local, state, and federal agencies, and significant technical challenges to implement in the shallow, tidally influenced conditions. Among the alternatives involving in-river construction, R3 may be the least administratively implementable because of concerns the permitting agencies may have for raising the river bottom elevation with capping materials. Alternative R4 is more implementable than Alternatives R5 or R6 because of the smaller dredge depth and correspondingly shorter time required to complete.

Although the removal and backfilling or capping activities in the river that are included in Alternatives R3 through R6 are challenging tasks, the equipment, materials, and skills needed to perform these actions are readily available. Application of the cap in Alternative R3 could be performed using several alternative methods and presents no significant implementation problems. Similar removal and cover actions have been implemented successfully at other sites with similar conditions.

6.2.7 Cost

The cost of implementation for the OU-3 river remedial alternatives rise in order from the least cost Alternative R1 at an estimated total present value of $0, to the highest cost, Alternative R6 at an estimated total present value of $13,500,000 (see Table 6-2).

7 Summary

In this feasibility study, Exponent has identified, developed, and evaluated remedial alternatives to address contaminated sediments in the Horseshoe Road/ARC OU-3 marsh and adjacent Raritan River areas. With the exception of the no action alternative, the overall remedial approach involves the excavation of contaminated sediments within the SPD/ADC drainage channel corridor combined with other remedial technologies (i.e., MNR, thin cover/capping, excavation/dredging) to address residual risk to environmental receptors in the marsh and river. Tables 7-1 and 7-2 present detailed summaries of the OU-3 marsh and river remedial alternatives, respectively, identifying estimated affected areas; excavation/dredge, cover/cap, and disposal volumes; and total estimated net present value costs.

Although the marsh and river remedial alternatives are evaluated separately in Sections 5 and 6 of this feasibility study, an overall OU-3 remedy will be selected for implementation that includes both a marsh remedial alternative and a river remedial alternative. The detailed analysis of alternatives found that all except the no action alternatives achieved the RAOs and all site-specific, risk-based PRGs. Distinguishing points between alternatives include:

- Length of time required to achieve the PRGs. Alternatives M2, M3, R2, and R5, which involve MNR, require more time to achieve the most restrictive PRGs (the overall site PRGs).
- Extent of disturbance and contaminated sediment volumes removed. Marsh Alternatives M4 through M7 and river Alternatives R3 through R6 disturb the largest areas, with marsh Alternatives M6 and M7 and river Alternatives R5 an R6 also removing the largest volumes. All of these alternatives also result in the most disruption of both the hydrologic and ecological features of the marsh and river for a longer period of time than the other alternatives.
- Potential administrative acceptability of the alternatives to permitting agencies. Marsh Alternatives M2, M4, M5, and M6 and river Alternative R3, involving placement of cover/capping materials, will slightly raise elevations, which is a consideration in this shallow flood plain environment.
- Costs to implement. Costs to implement marsh Alternatives M4 through M7 and river Alternatives R5 and R6 are substantially higher than the other alternatives, and are approximately twice the cost of the next highest alternatives (Alternatives M3 and R4, respectively).

A matrix summary of the estimated total net present value costs for the OU-3 marsh and river remedial alternatives is presented in Table 7-3 to provide total estimated OU-3 remediation costs for all possible combinations of OU-3 marsh and river remedial alternatives. These total costs are presented graphically from lowest to highest in Figure 7-1.

The lowest cost combination of remedial alternatives that achieves all RAOs and PRGs is Alternatives M2 + R2 (SPD/ADC channel excavation, thin cover sediments > 160 mg/kg arsenic, and MNR of both the marsh and river) at $8,070,000. Alternatives M2 and R2 rely on natural recovery processes such as sediment deposition and plant detritus buildup, which may be accelerated by the removal of the highest contaminated and most mobile sediments in the SPD/ADC drainage and the containment of the adjacent, moderately contaminated marsh sediments. Additional data collection during the design phase would permit refinement of estimates of recovery. As typically required for MNR remedies, these alternatives would be closely monitored during implementation to ensure that rates of recovery are acceptable. Finally, contingency actions defined in the feasibility study (i.e., additional thin cover/excavation for the marsh and capping/dredging for the river) would be available if rates of recovery are deemed unacceptable based on additional data collection and monitoring.

These alternatives are both beneficial to the environment and consistent with the NCP and appropriate CERCLA guidance including:

- *Presumptive Remedy for Metals-in-Soil Sites* (U.S. EPA 1999)
- *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (U.S. EPA 2005).

The lowest cost combination that does not include MNR is Alternatives M4 + R3 (shallow hot spot removal and thin cover in the marsh and shallow dredge sediments >194 mg/kg arsenic and thin cap in the river) at $17,800,000; (approximately double the Alternatives M2 + R2 combination). The lowest cost combination that does not include MNR and does not increase sediment surface elevations is Alternatives M7 + R4 (complete removal in the marsh and extended shallow dredge in the river). The total estimated cost for this combination is $26,300,000; an increase of approximately $9 million over the Alternatives M4 + R3 combination and more than three times the Alternatives M2 + R2 combination.

Finally, the highest cost combination is Alternatives M7 + R6 (complete removal of both marsh and river sediments) at $34,200,000. This is an increase of almost $8 million over the Alternatives M7 + R4 combination and approximately four times the lowest cost combination of Alternatives M2 + R2.

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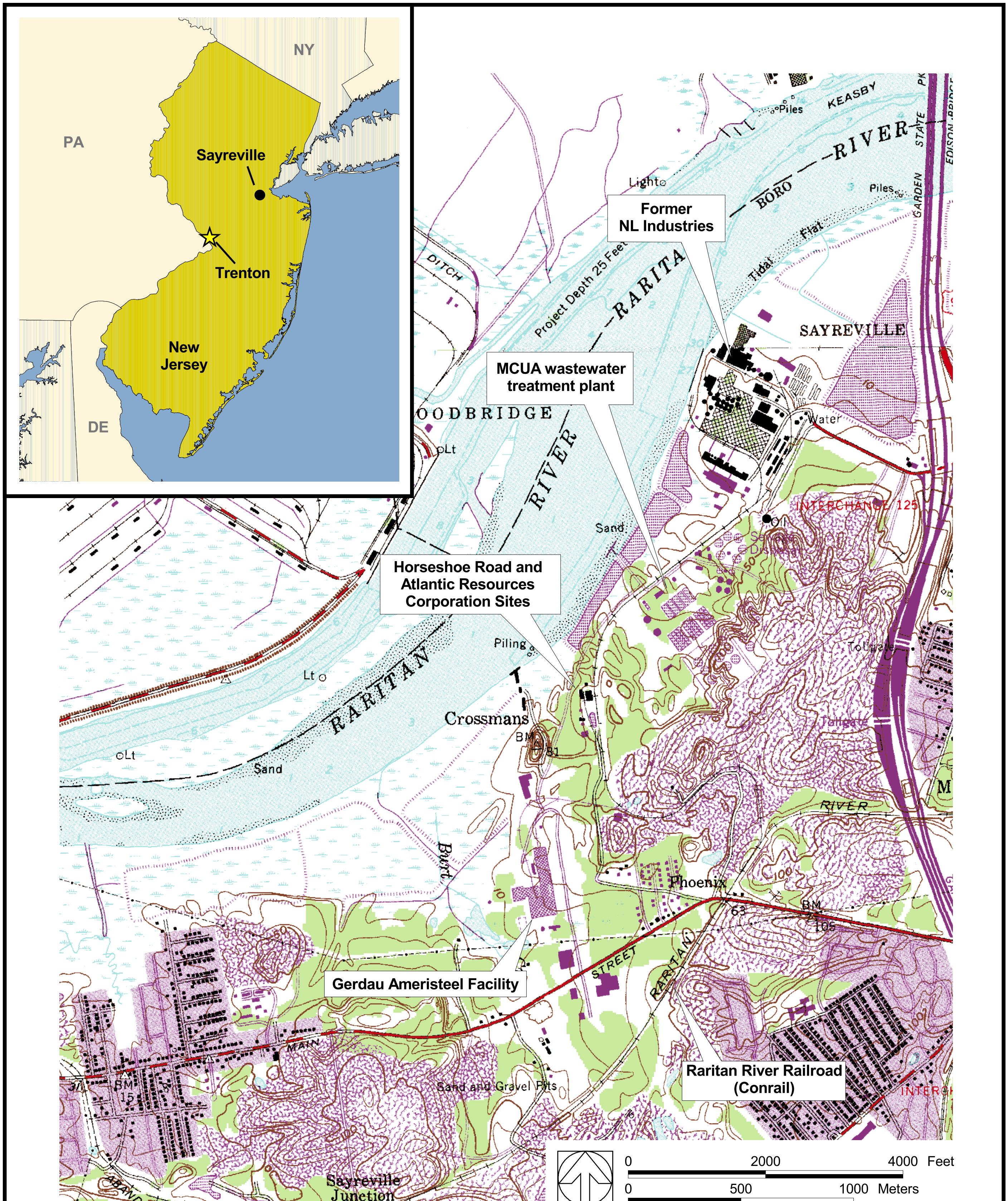
Figures



Source: Base map from USGS topographic map South Amboy (1981) and Perth Amboy (1981).

Figure 1-1. Location of Horseshoe Road and Atlantic Resources Corporation Sites

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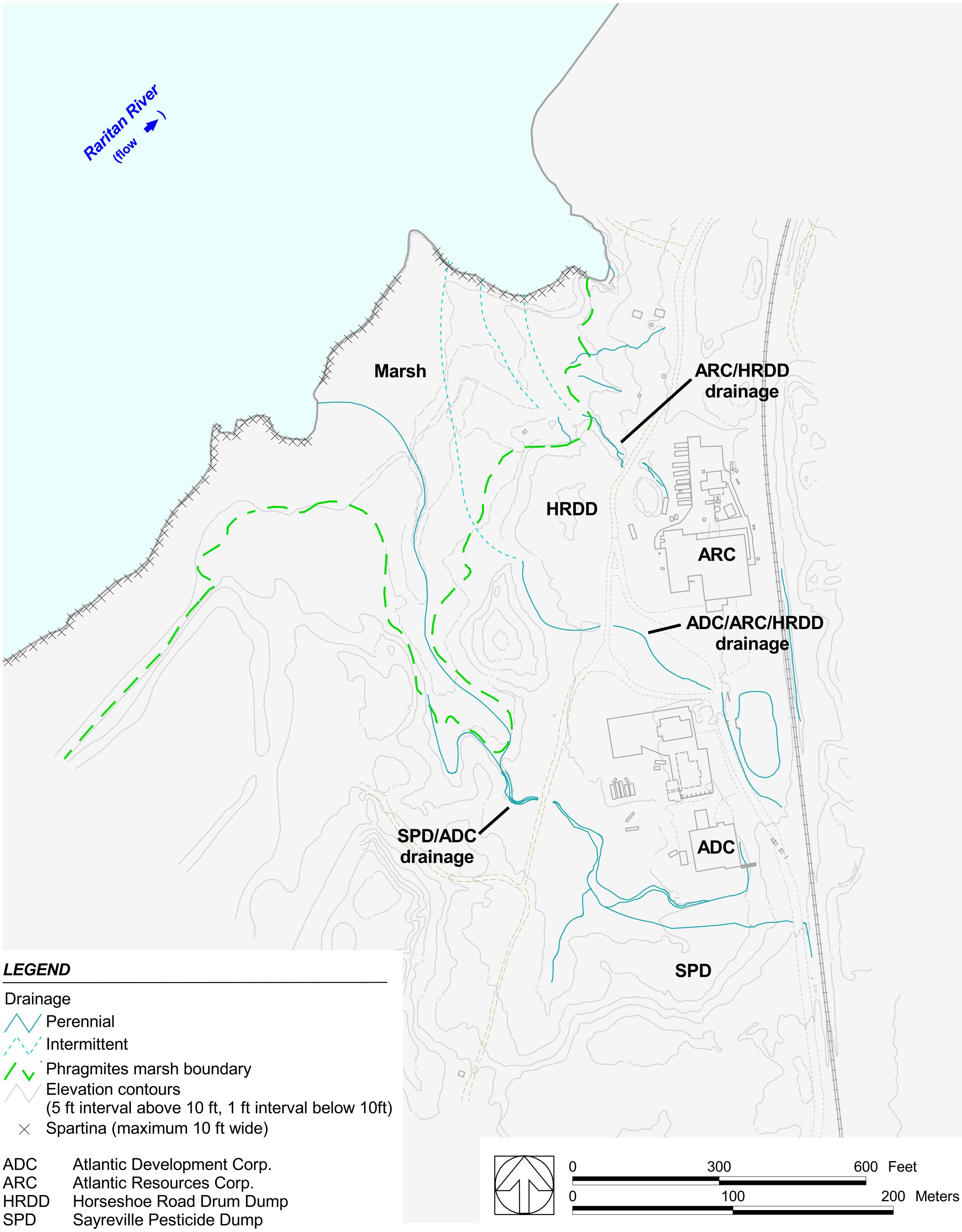

Note: All buildings have been demolished. Figure shows former locations.

Figure 1-2. Details of the Horseshoe Road and Atlantic Resources Corporation Sites

Exponent®

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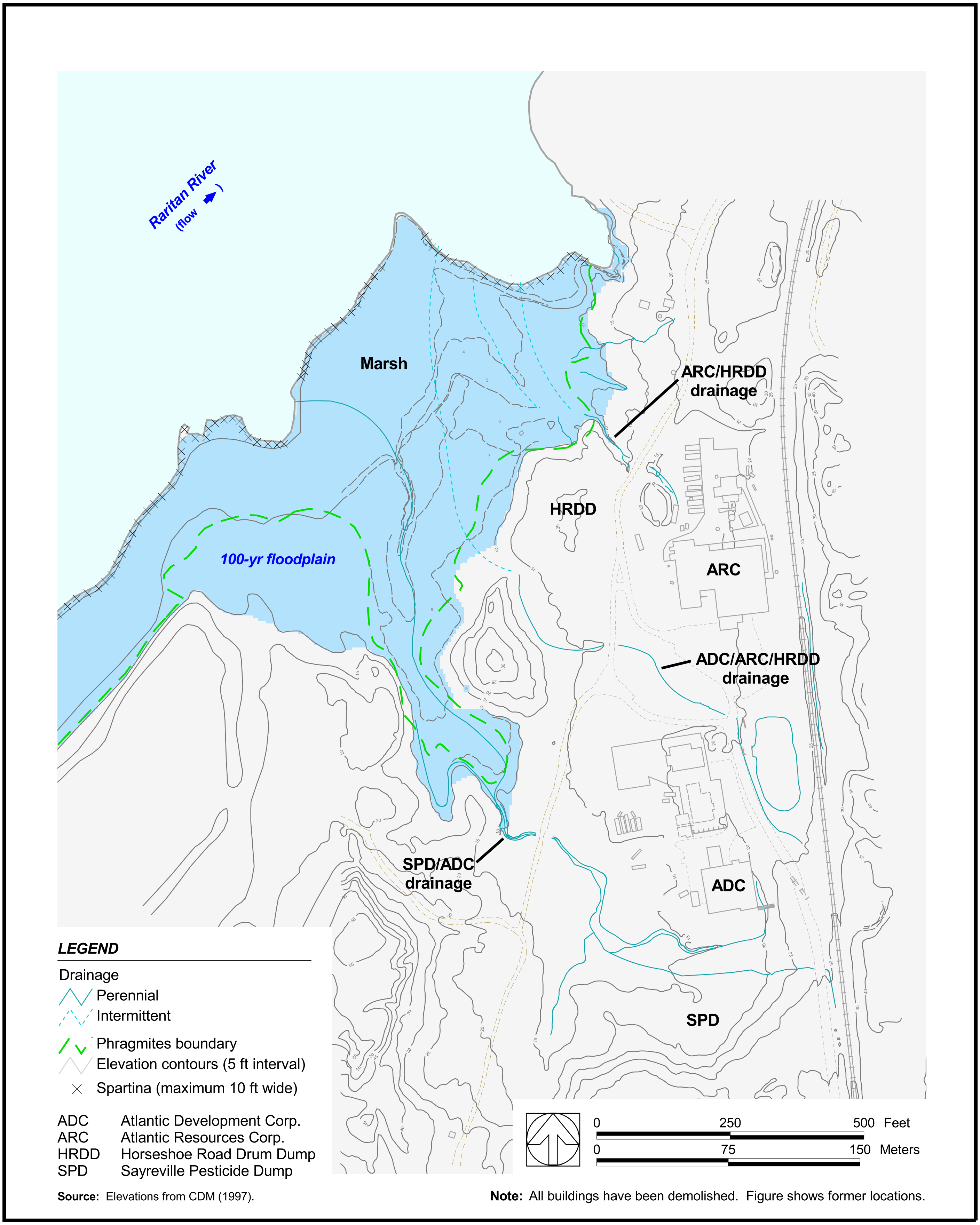

Figure 1-3. Extent of 100-year floodplain

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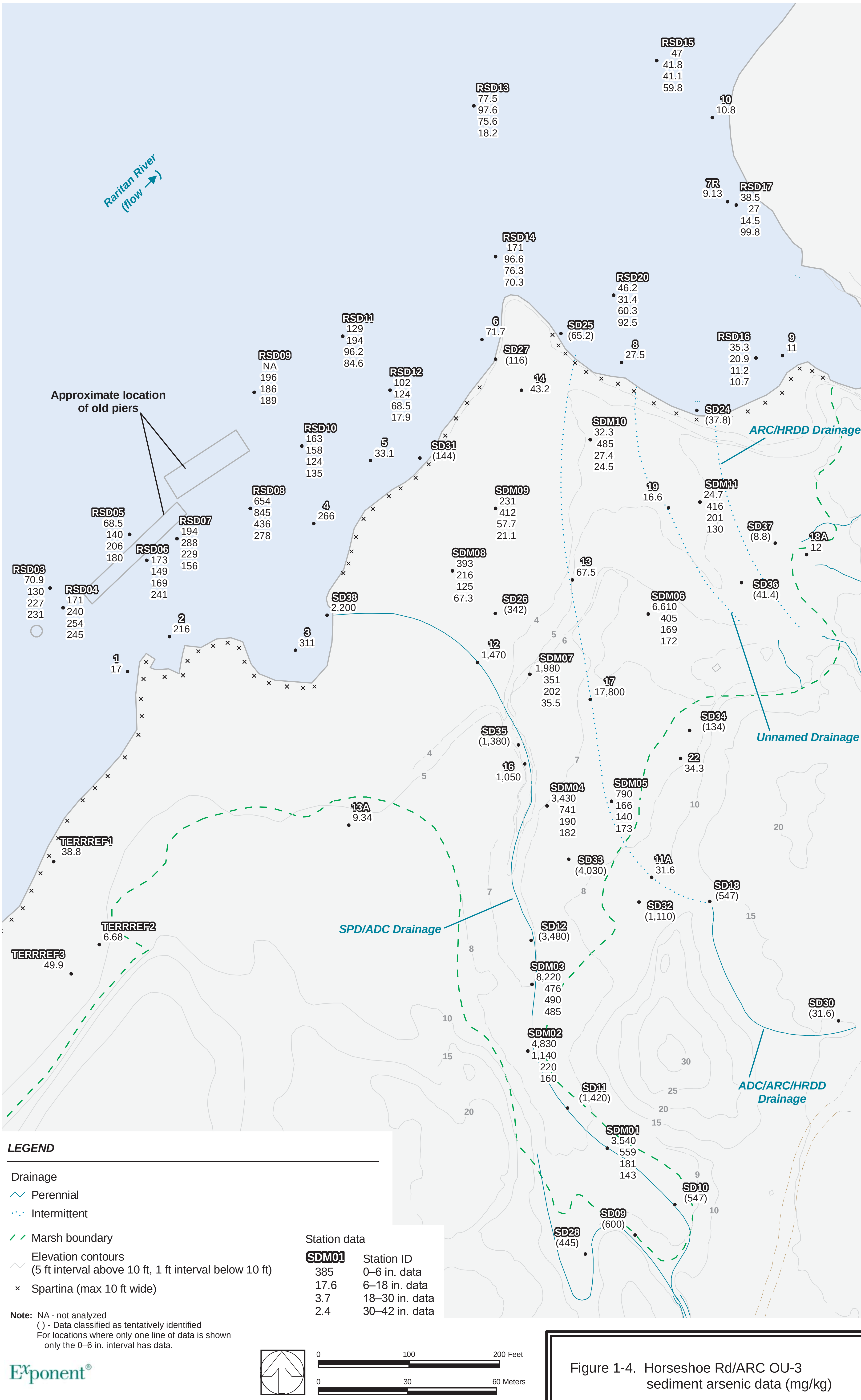

Figure 1-4. Horseshoe Rd/ARC OU-3
sediment arsenic data (mg/kg)

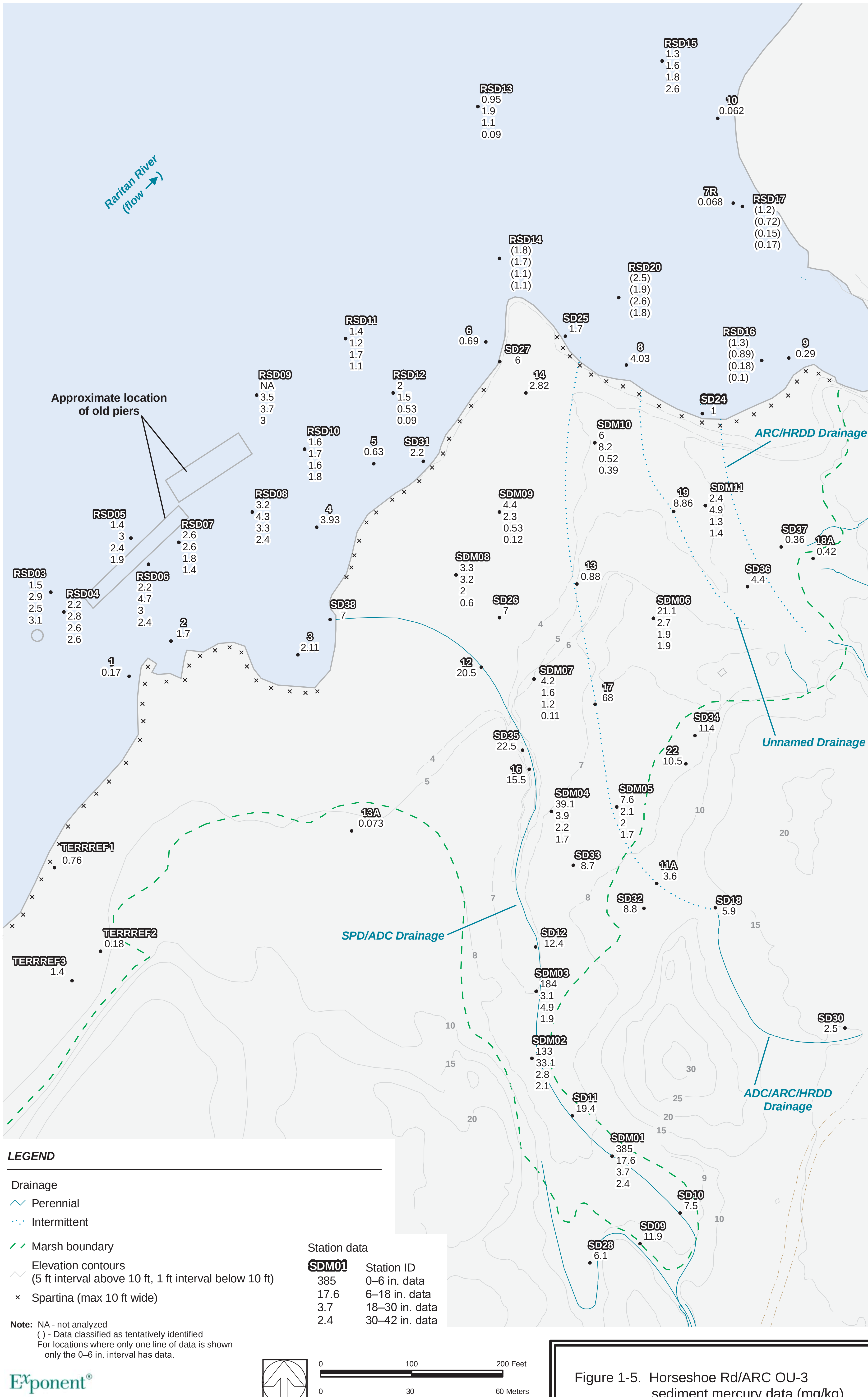

Figure 1-5. Horseshoe Rd/ARC OU-3 sediment mercury data (mg/kg)

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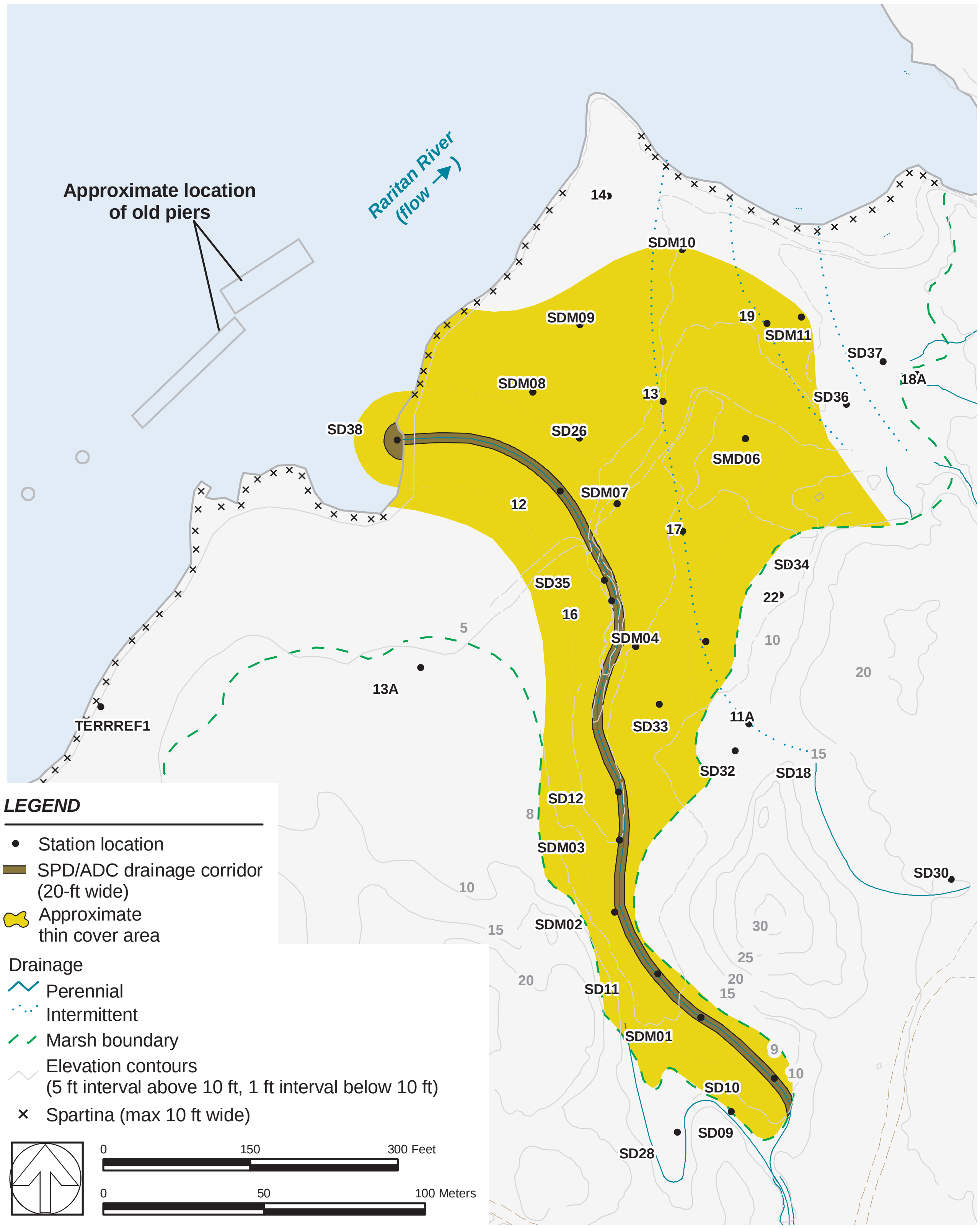

Figure 4-1. Alternative M2—Channel excavation and thin cover

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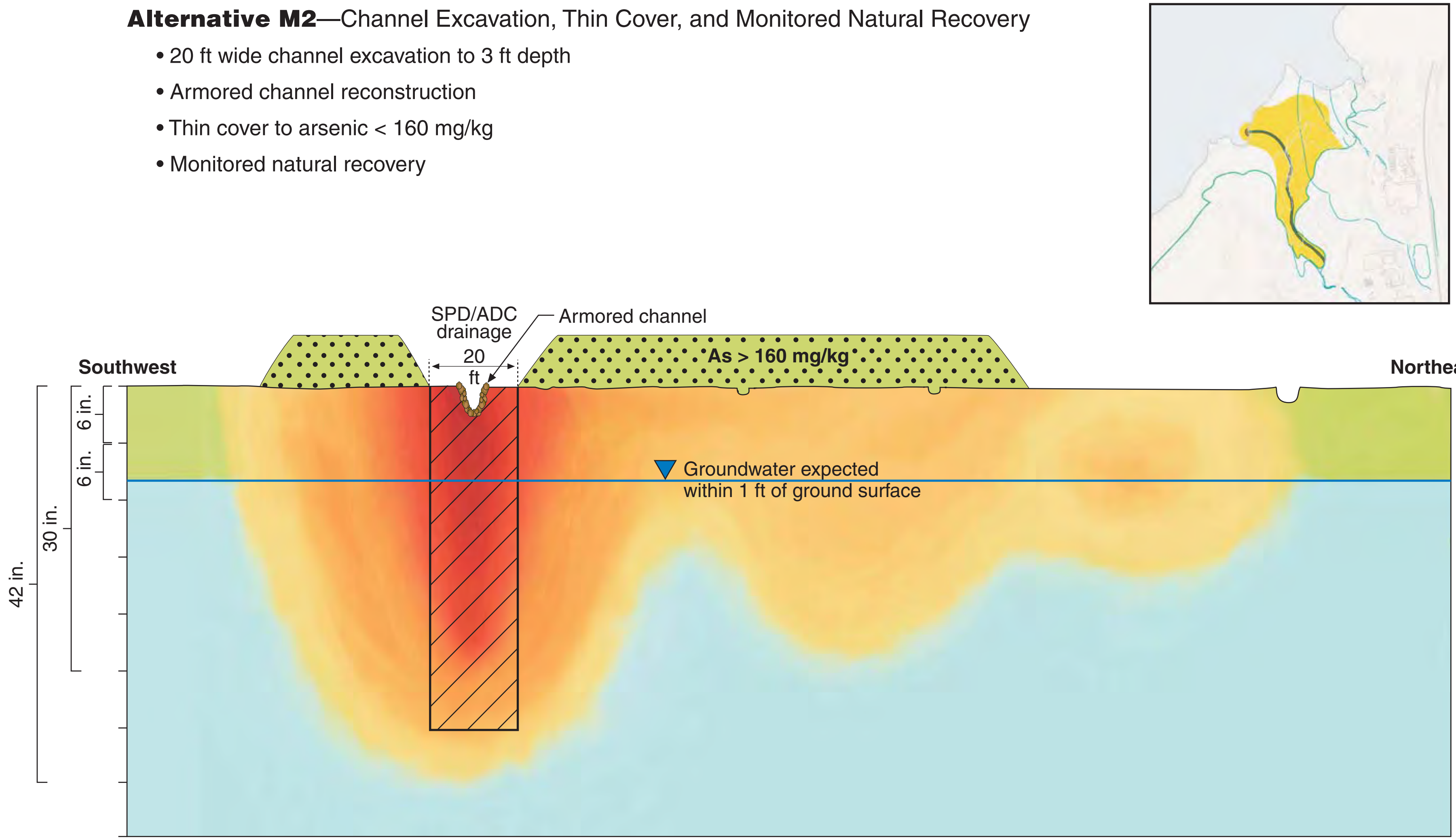
Alternative M2—Channel Excavation, Thin Cover, and Monitored Natural Recovery

- 20 ft wide channel excavation to 3 ft depth
- Armored channel reconstruction
- Thin cover to arsenic < 160 mg/kg
- Monitored natural recovery



Estimated in-place excavation volume: 2,000 yd^3

Approximate area excavated: 0.3 acres

Estimated area backfilled/covered: 4.6 acres

LEGEND

- Backfill/cover
- Thin cover/cap

Conceptual degree of contamination

High — Low

Figure 4-2. Conceptual model for Alternative M2

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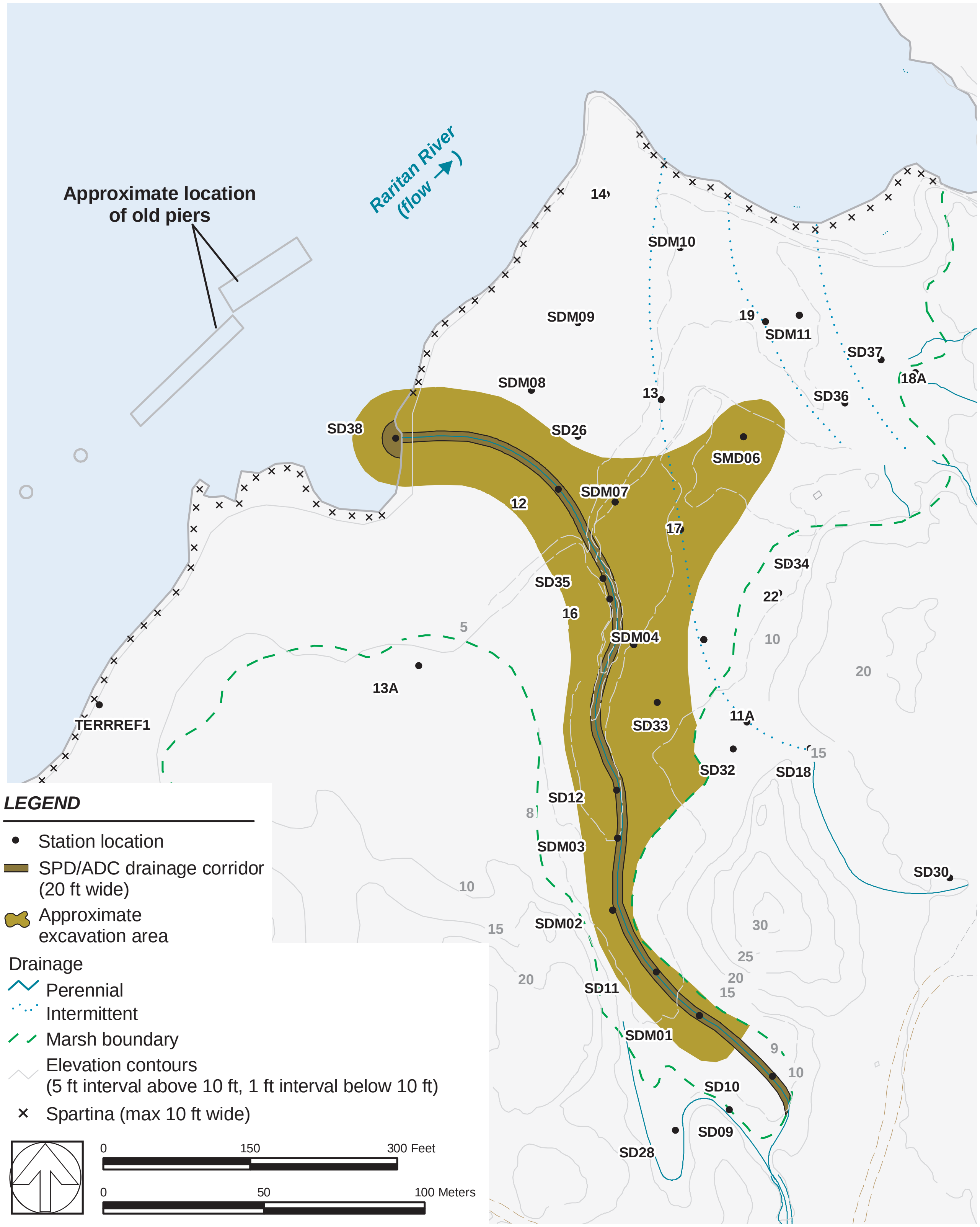

Figure 4-3. Alternative M3—Surficial hot spot removal and monitored natural recovery

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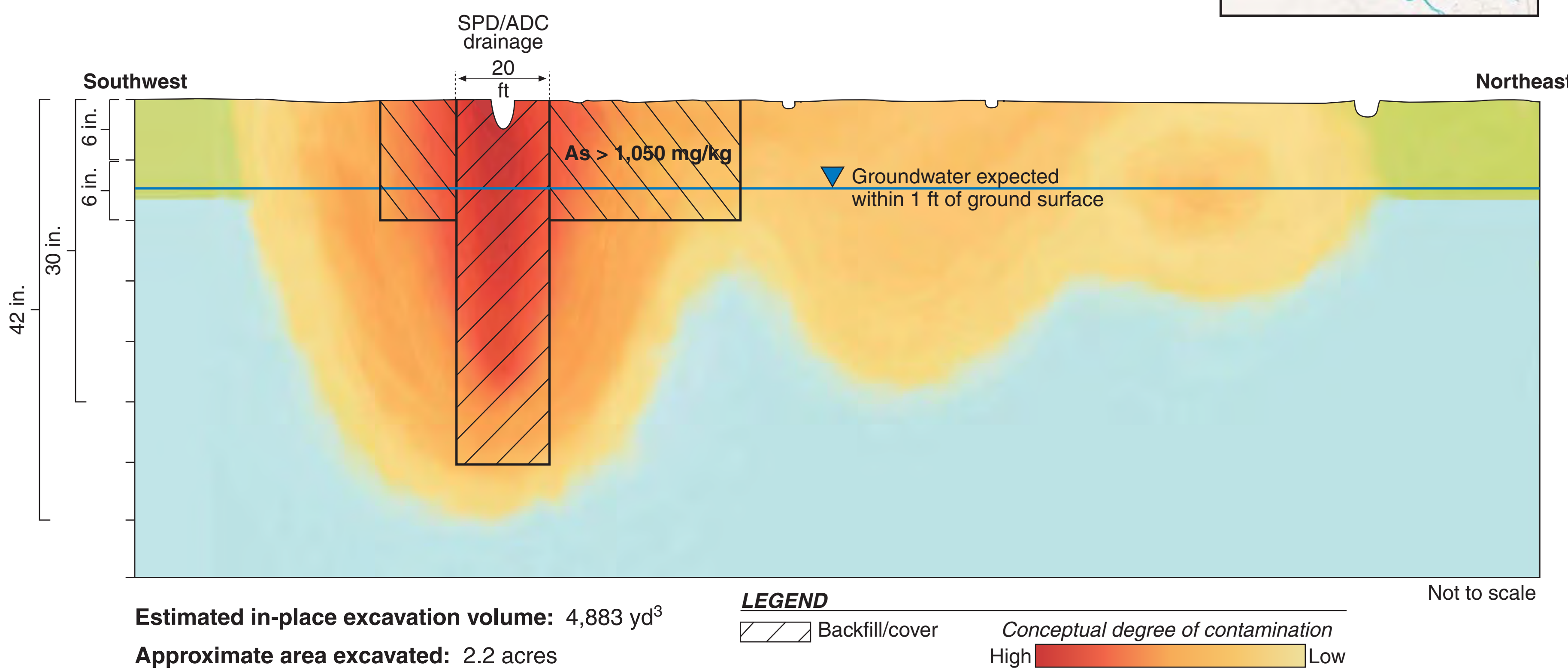
Alternative M3—Surficial Hot Spot Removal and Monitored Natural Recovery

- 20 ft wide channel excavation to 3 ft depth
- 1 ft excavation and backfill to arsenic < 1,050 mg/kg
- Monitored natural recovery



Estimated in-place excavation volume: 4,883 yd^3

Approximate area excavated: 2.2 acres

Estimated area backfilled/covered: 0 acres

Figure 4-4. Conceptual model for Alternative M3

BE02578.001 1107 07/01/08 WA

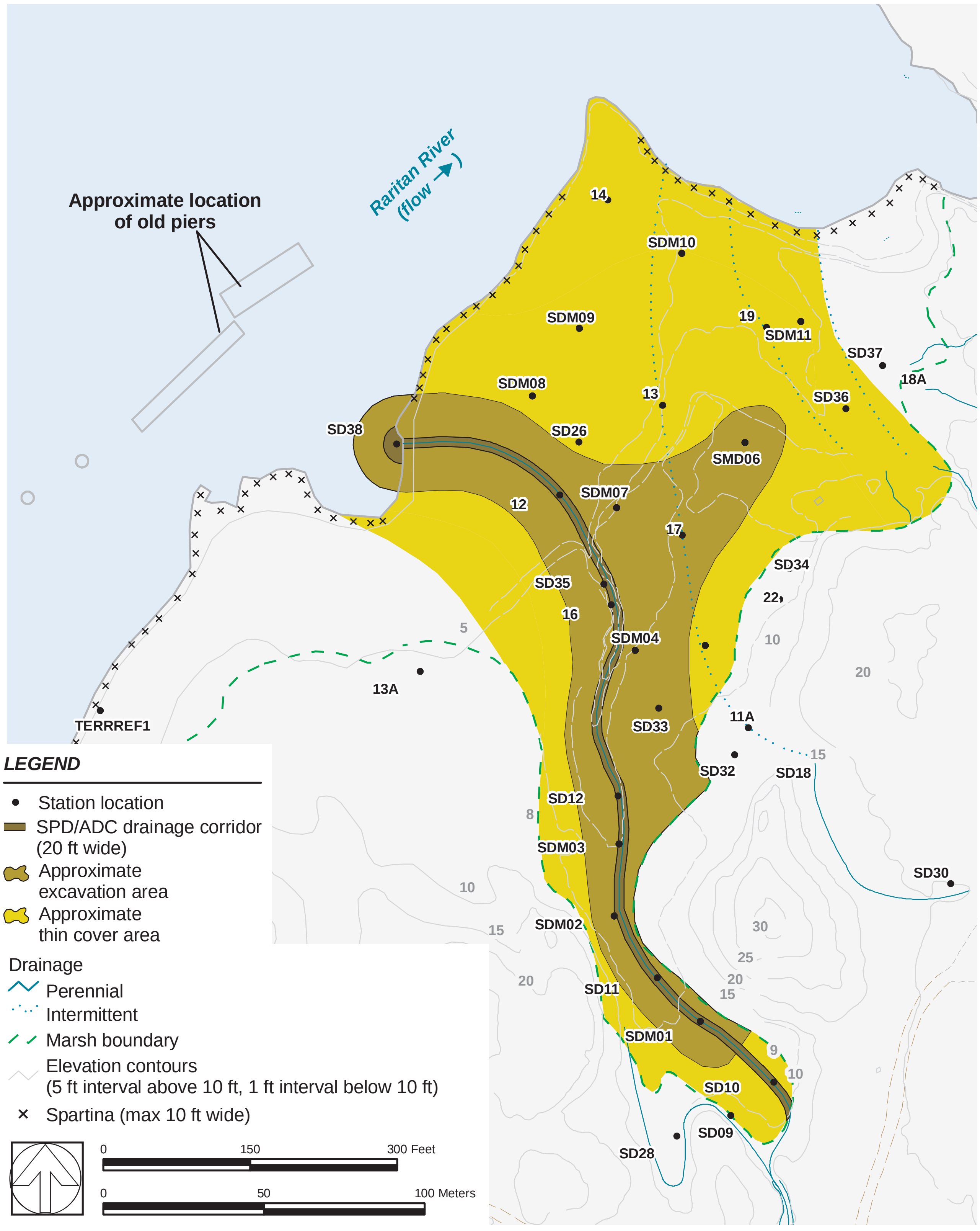


Figure 4-5. Alternative M4—Shallow hot spot removal and thin cover

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BE02578 | February 14, 2008 | M:\BE02578_Sayreville\projects\alternative figures - M4.mxd

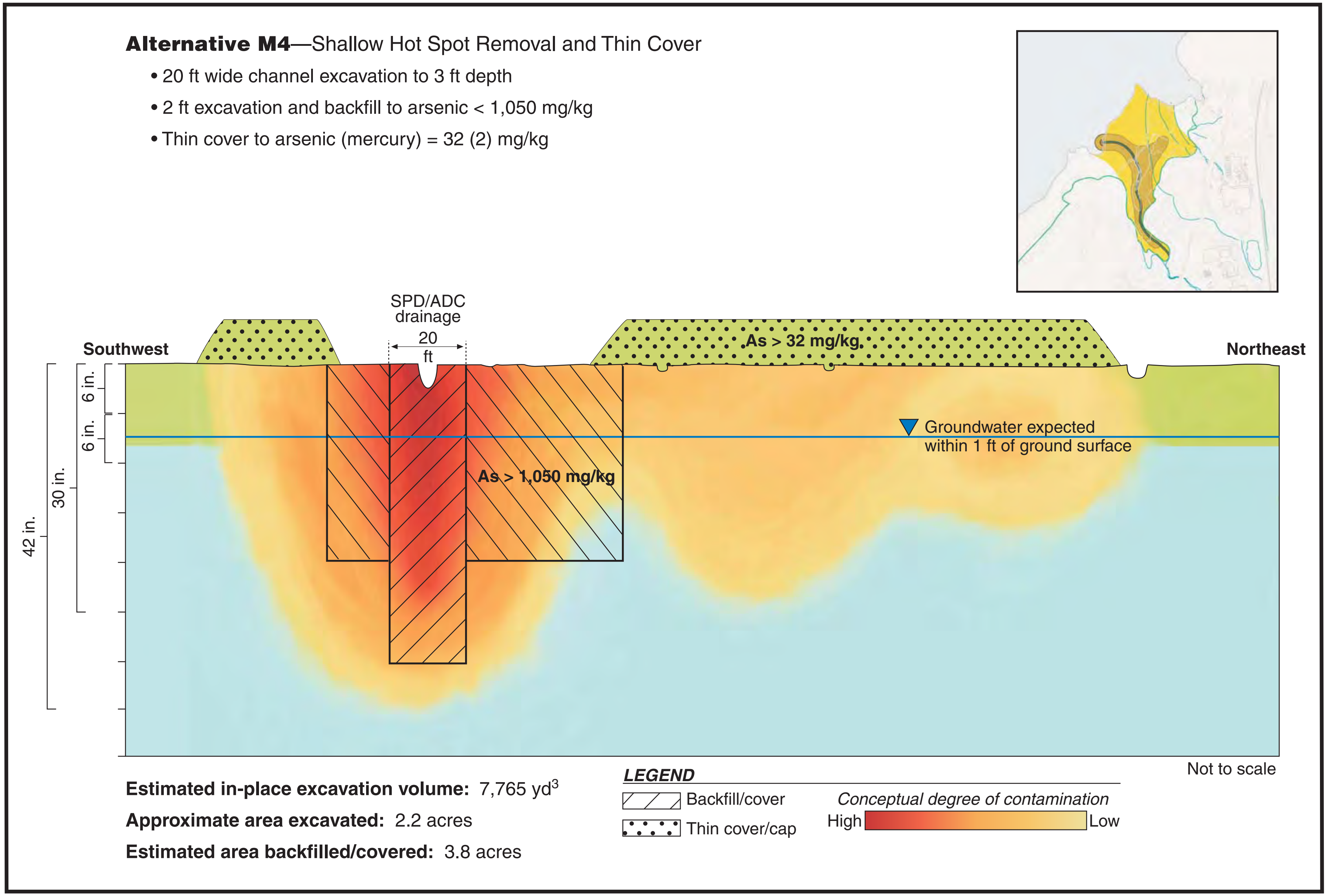
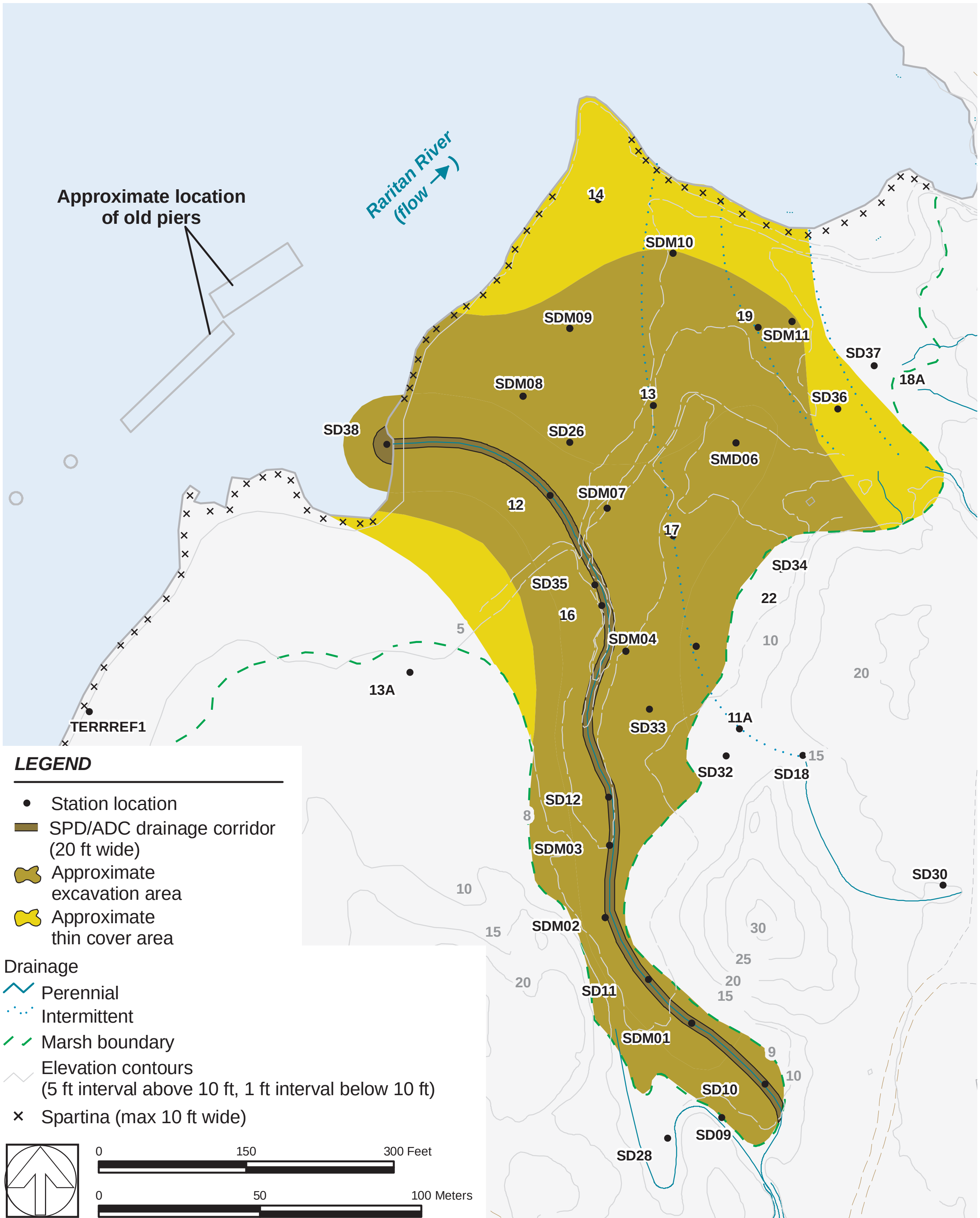


Figure 4-6. Conceptual model for Alternative M4

BE02578.001 1107 07/01/08 WA



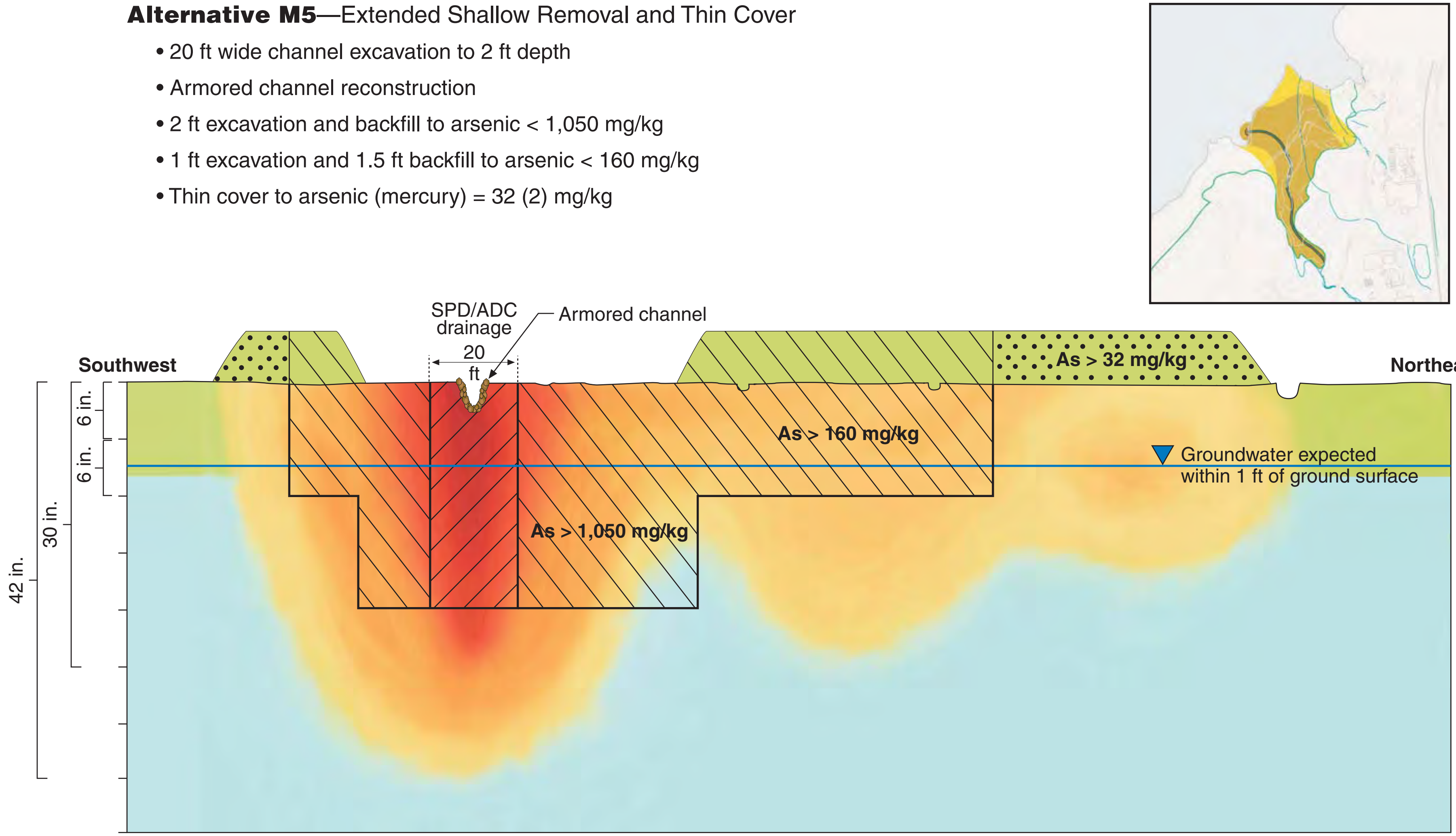
Note: The surficial extents shown in this figure are the same for Alternative M6.

Figure 4-7. Alternative M5—Extended shallow removal and thin cover
Alternative M6—Extended deep removal and thin cover

Exponent®

Alternative M5—Extended Shallow Removal and Thin Cover

- 20 ft wide channel excavation to 2 ft depth
- Armored channel reconstruction
- 2 ft excavation and backfill to arsenic < 1,050 mg/kg
- 1 ft excavation and 1.5 ft backfill to arsenic < 160 mg/kg
- Thin cover to arsenic (mercury) = 32 (2) mg/kg



Estimated in-place excavation volume: 10,971 yd^3

Approximate area excavated: 4.6 acres

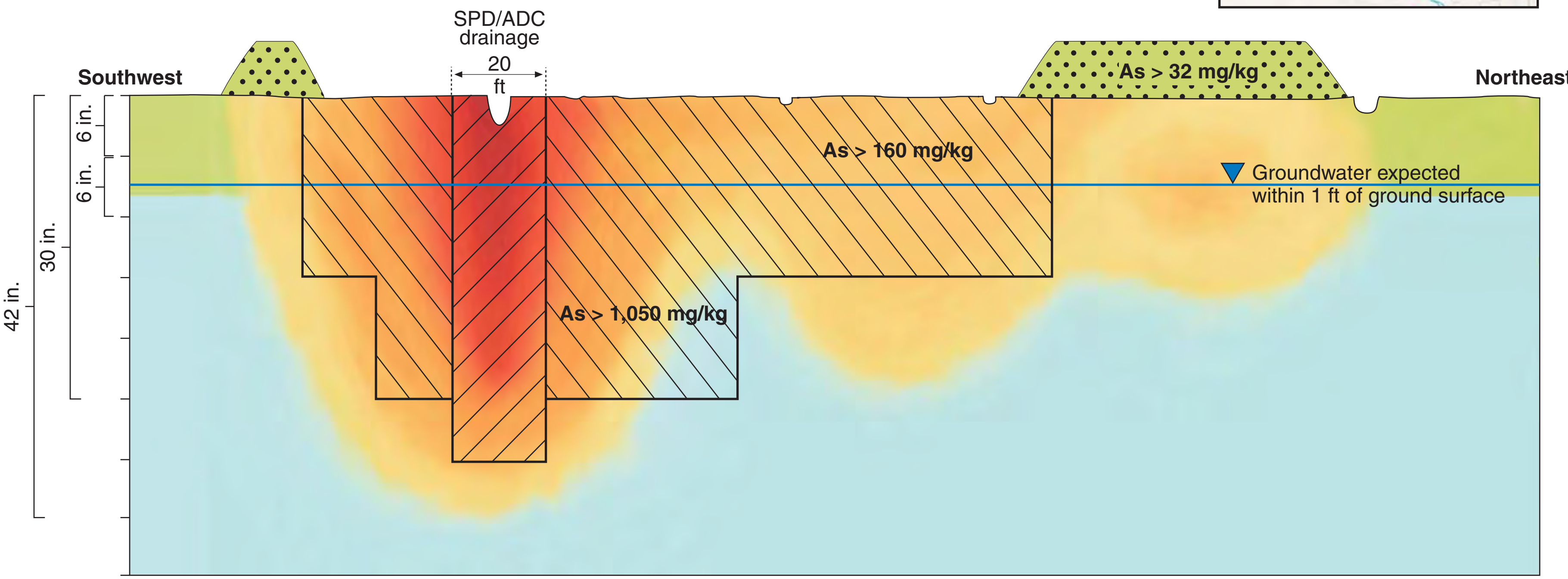
Estimated area backfilled/covered: 1.4 acres

Figure 4-8. Conceptual model for Alternative M5

BE02578.001 1107 07/01/08 WA

Alternative M6—Extended Deep Removal and Thin Cover

- 20 ft wide channel excavation to 3 ft depth
- 2.5 ft excavation and backfill to arsenic < 1,050 mg/kg
- 1.5 ft excavation and backfill to arsenic < 160 mg/kg
- Thin cover to arsenic (mercury) = 32 (2) mg/kg



Estimated in-place excavation volume: 15,015 yd^3

Approximate area excavated: 4.6 acres

Estimated area backfilled/covered: 1.4 acres

LEGEND

Backfill/cover

Thin cover/cap

Conceptual degree of contamination

High — Low

Figure 4-9. Conceptual model for Alternative M6

BE02578.001 1107 07/01/08 WA

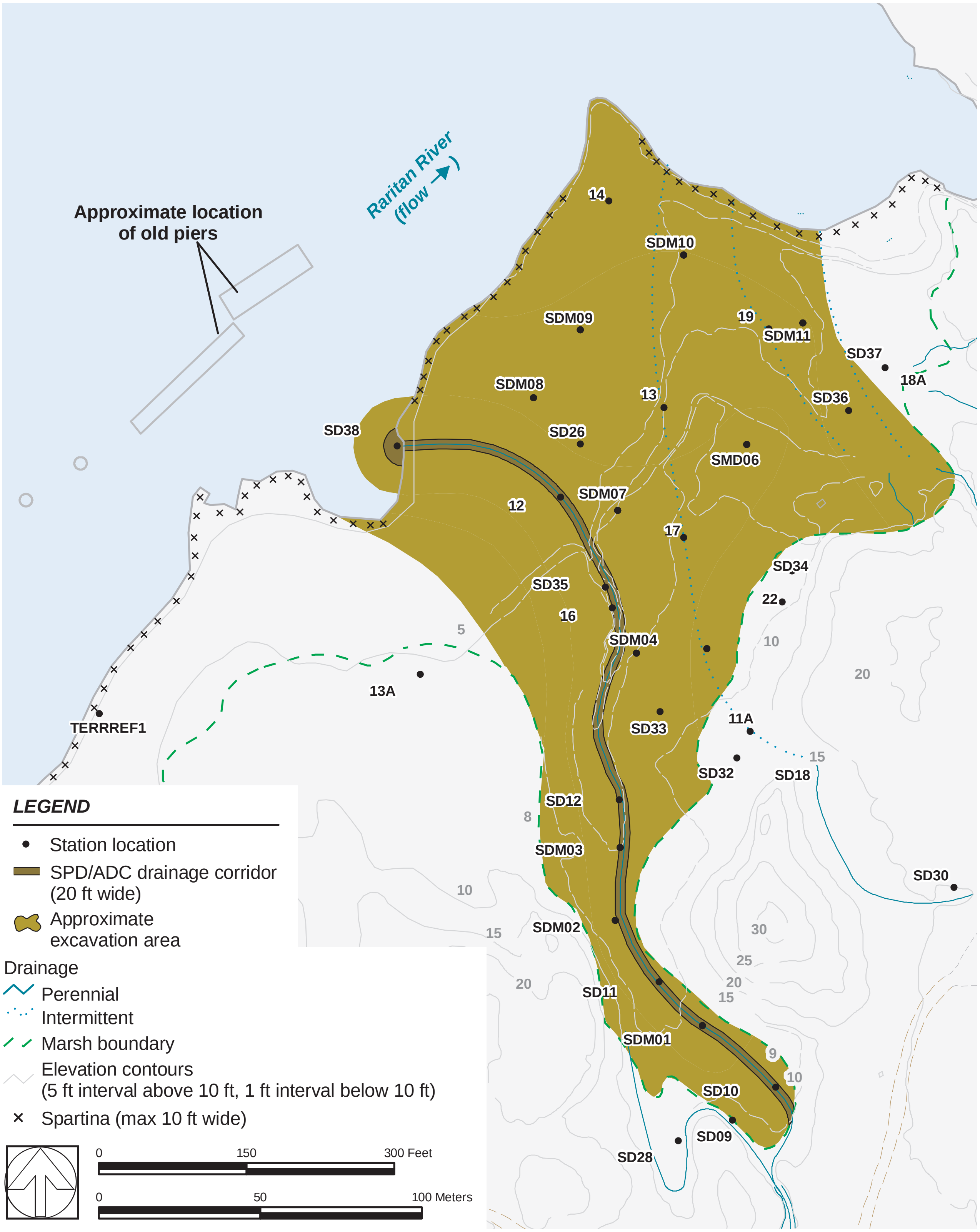
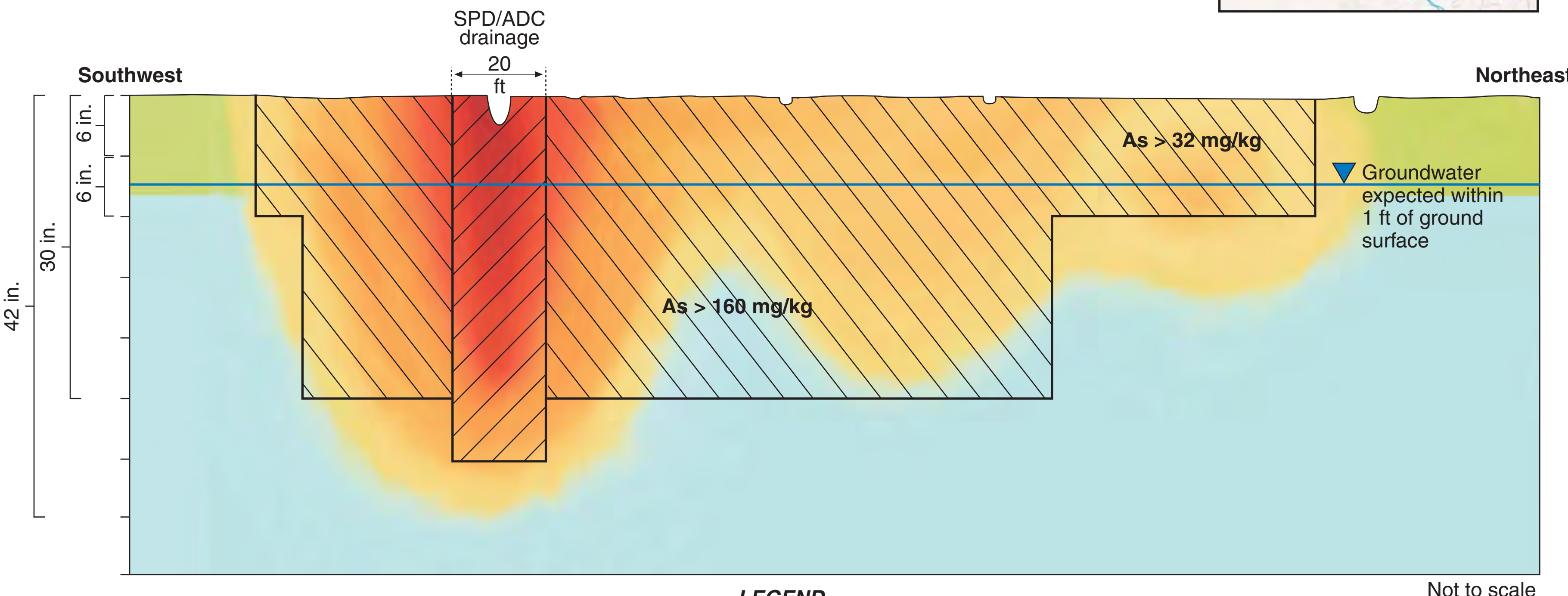


Figure 4-10. Alternative M7—Complete removal

Exponent®

Alternative M7—Complete Removal

- 20 ft wide channel excavation to 3 ft depth
- 2.5 ft excavation and backfill to arsenic < 160 mg/kg
- 1 ft excavation and backfill to arsenic (mercury) = 32 (2) mg/kg



Estimated in-place excavation volume: 21,145 yd^3

Approximate area excavated: 6 acres

Estimated area backfilled/covered: 0 acres

LEGEND

Backfill/cover

Conceptual degree of contamination

High — Low

Figure 4-11. Conceptual model for Alternative M7

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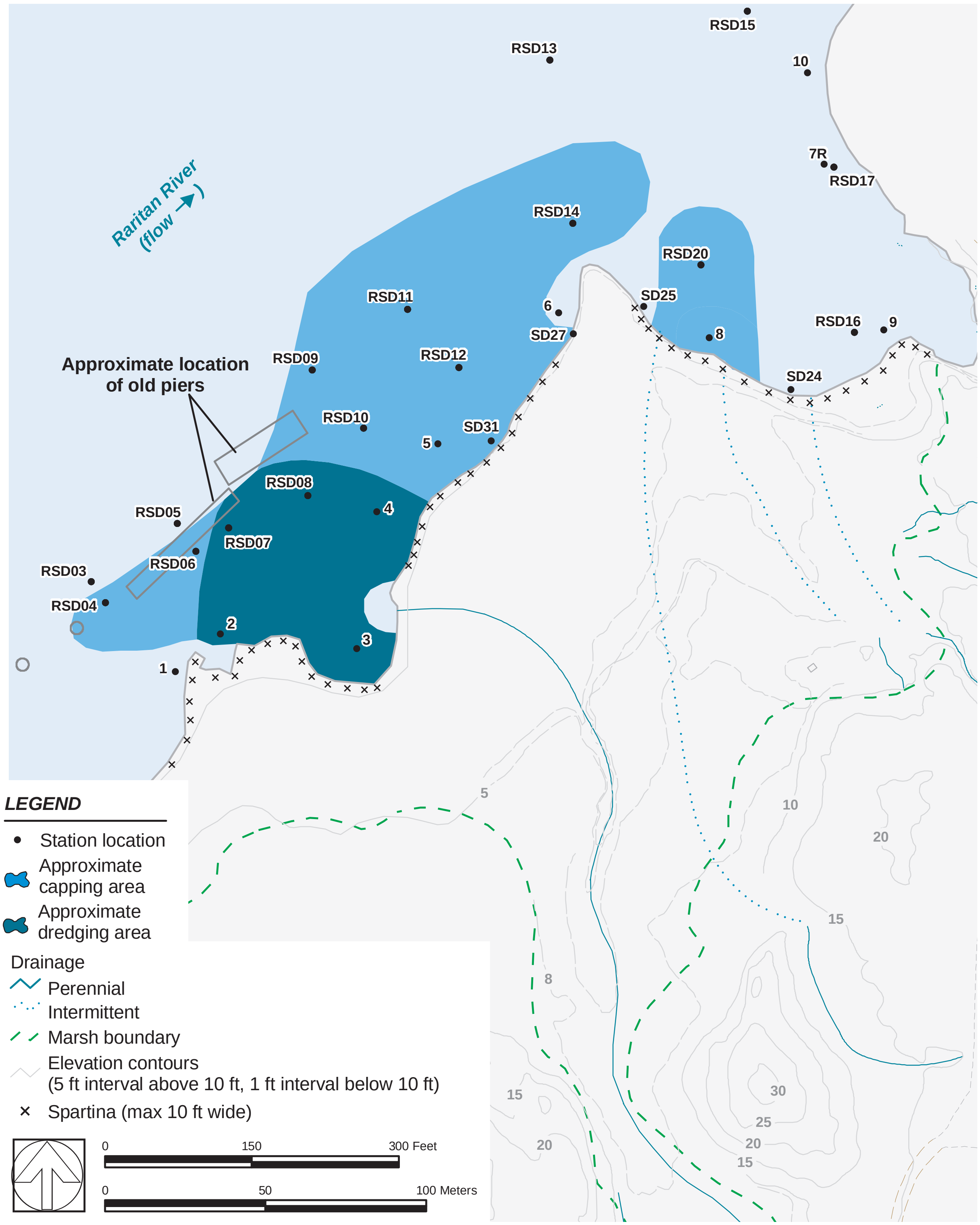

Figure 4-12. Alternative R3—Shallow dredge and thin cap

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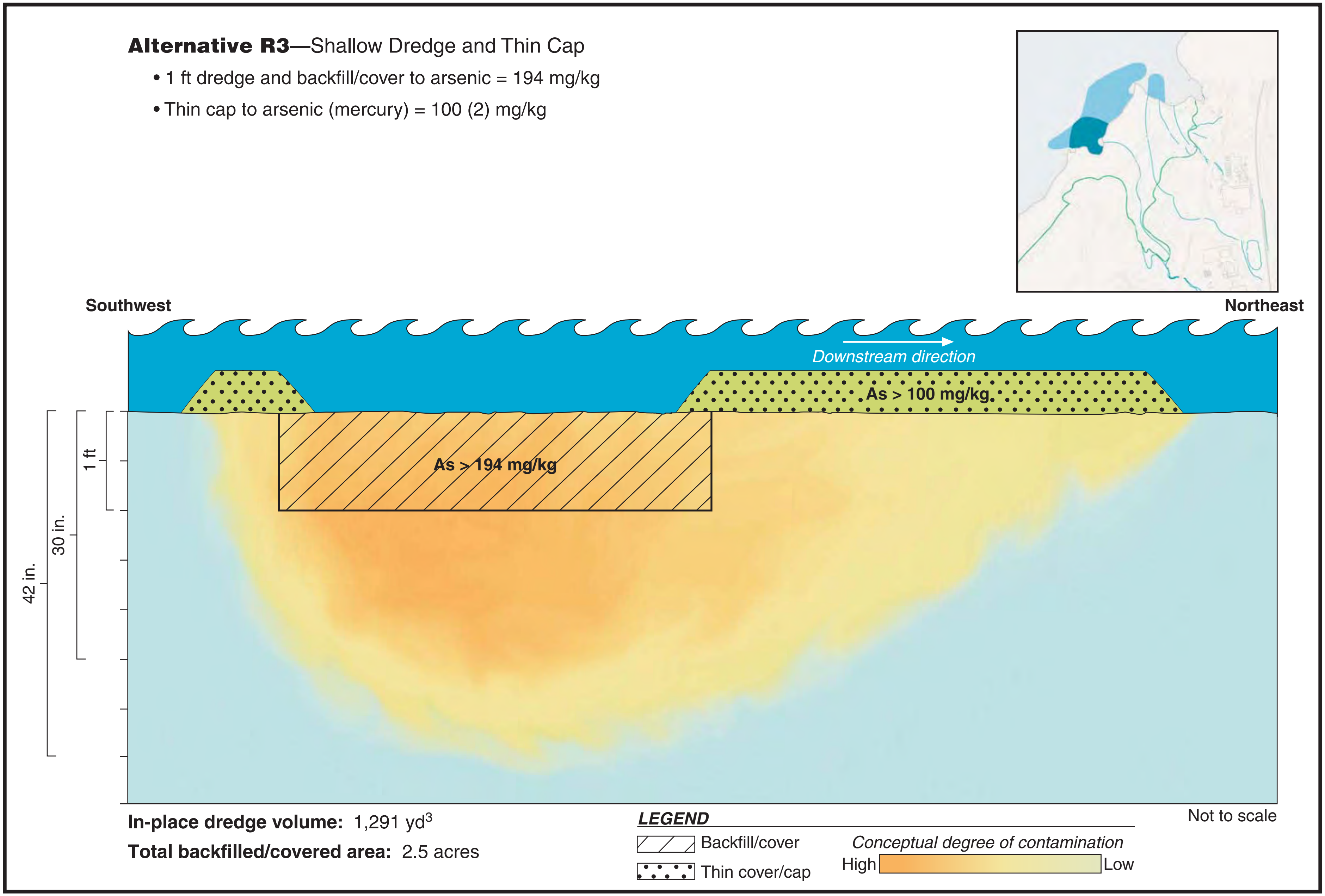

Figure 4-13. Conceptual model for Alternative R3

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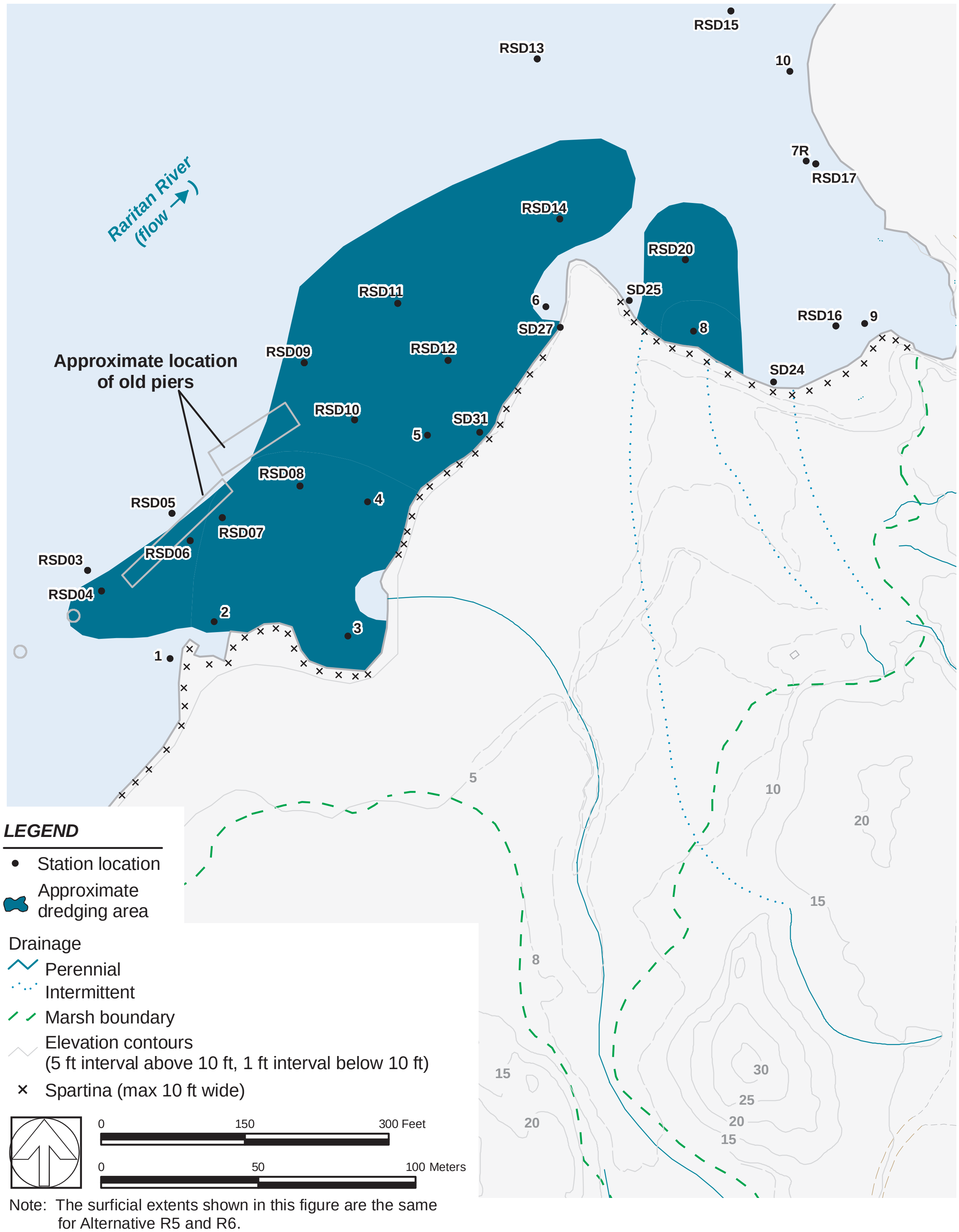


Figure 4-14. Alternative R4—Extended shallow dredge
Alternative R5—Deep dredge and monitored natural recovery
Alternative R6—Deep dredge and cover

Exponent®

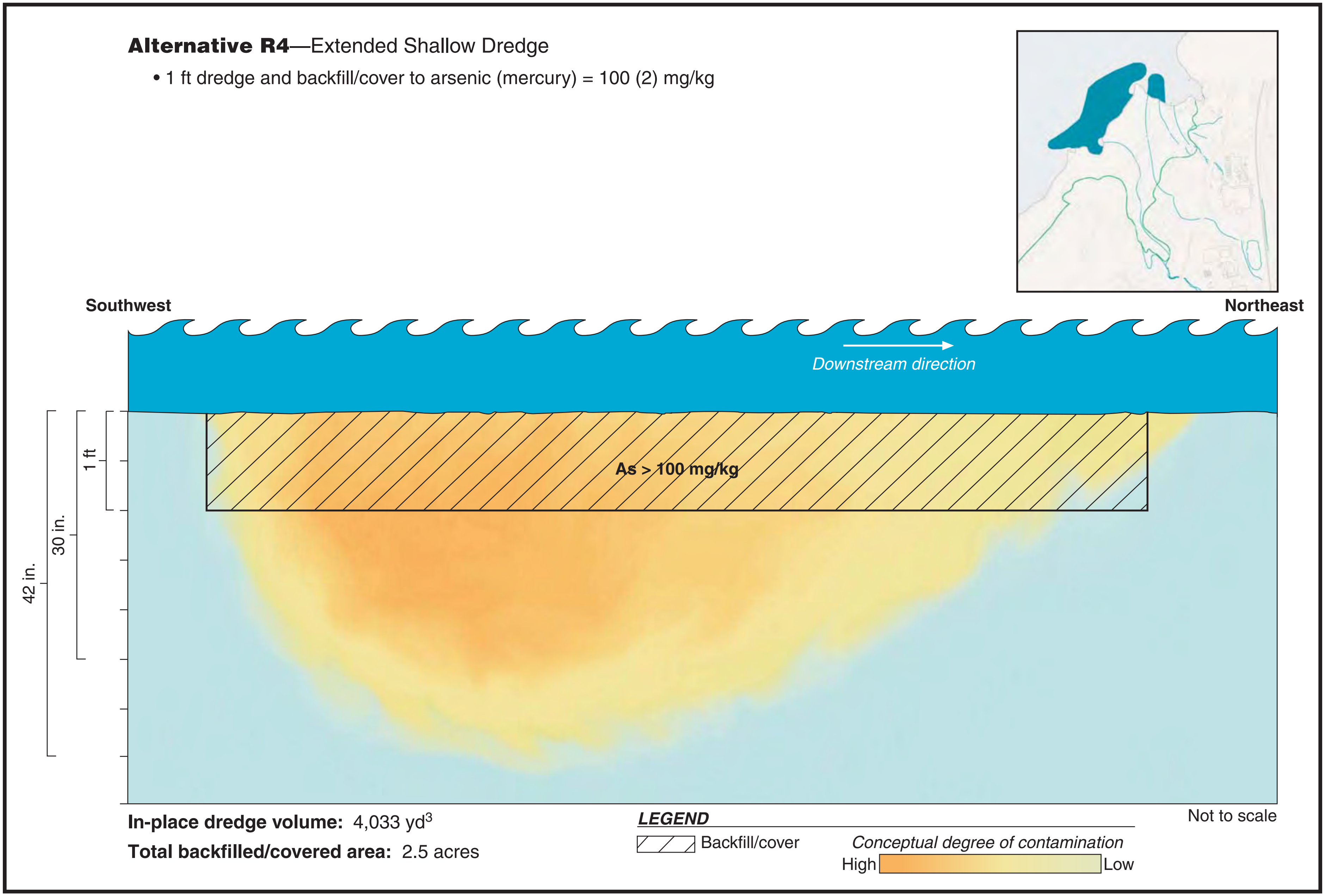
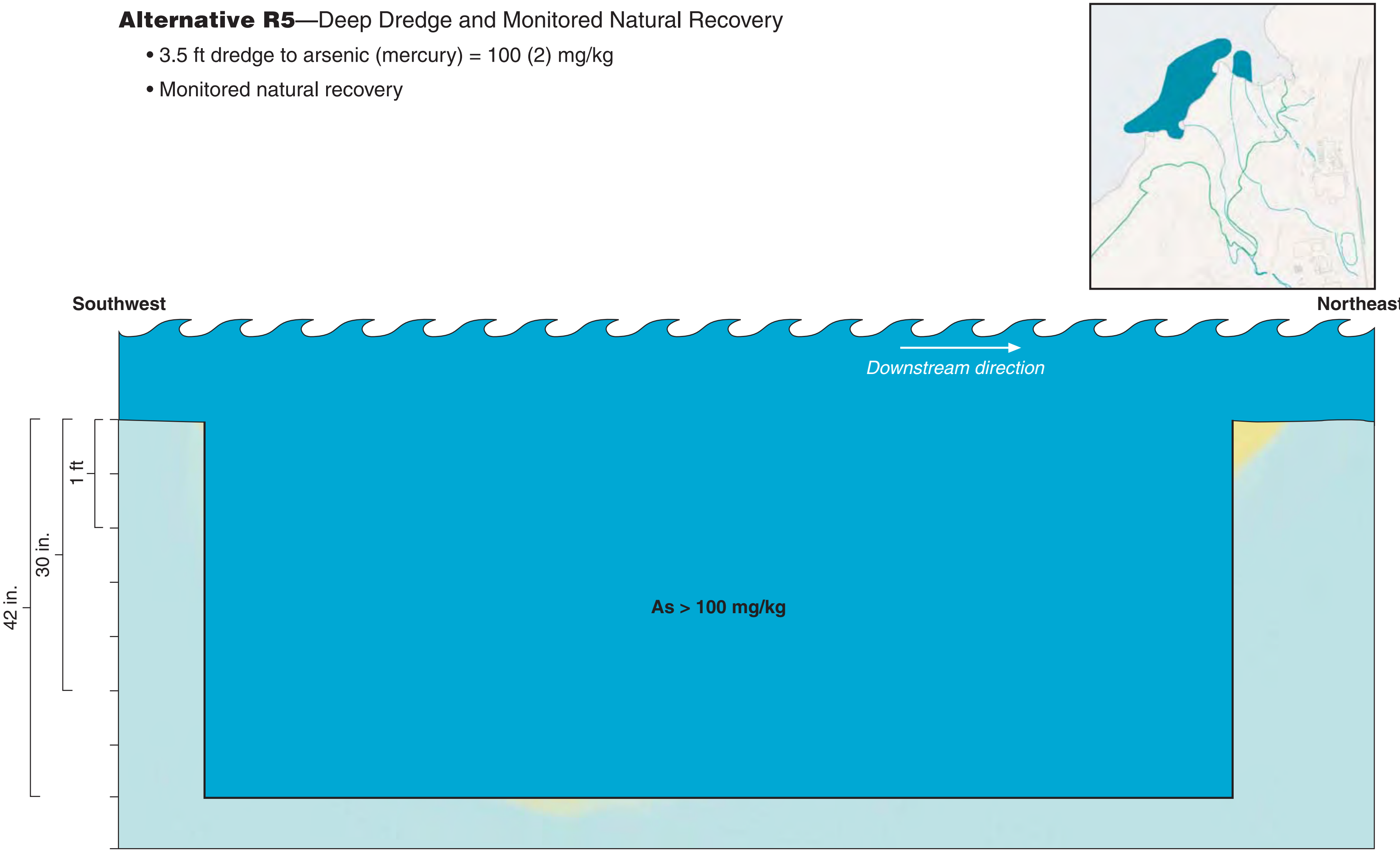


Figure 4-15. Conceptual model for Alternative R4

BE02578.001 1107 07/01/08 WA

Alternative R5—Deep Dredge and Monitored Natural Recovery

- 3.5 ft dredge to arsenic (mercury) = 100 (2) mg/kg
- Monitored natural recovery



In-place dredge volume: 14,117 yd^3

Total dredge area: 2.5 acres

LEGEND

Conceptual degree of contamination

High — Low

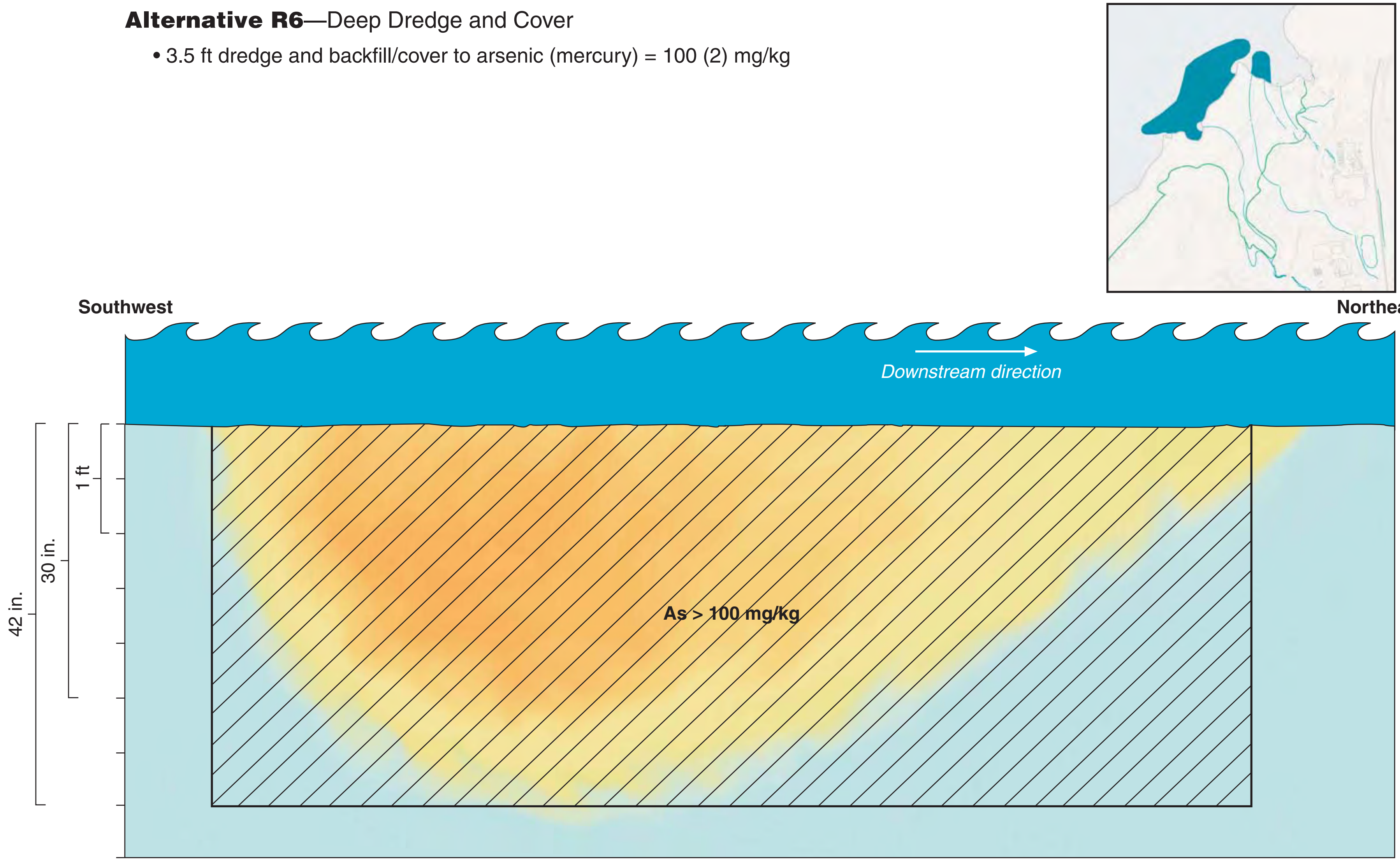
Not to scale

Figure 4-16. Conceptual model for Alternative R5

BE02578.001 1107 07/01/08 WA

Alternative R6—Deep Dredge and Cover

- 3.5 ft dredge and backfill/cover to arsenic (mercury) = 100 (2) mg/kg



In-place dredge volume: 14,117 yd^3

Total backfilled/covered area: 2.5 acres

Not to scale

LEGEND

Backfill/cover

Conceptual degree of contamination

High — Low

Figure 4-17. Conceptual model for Alternative R6

BE02578.001 1107 07/01/08 WA

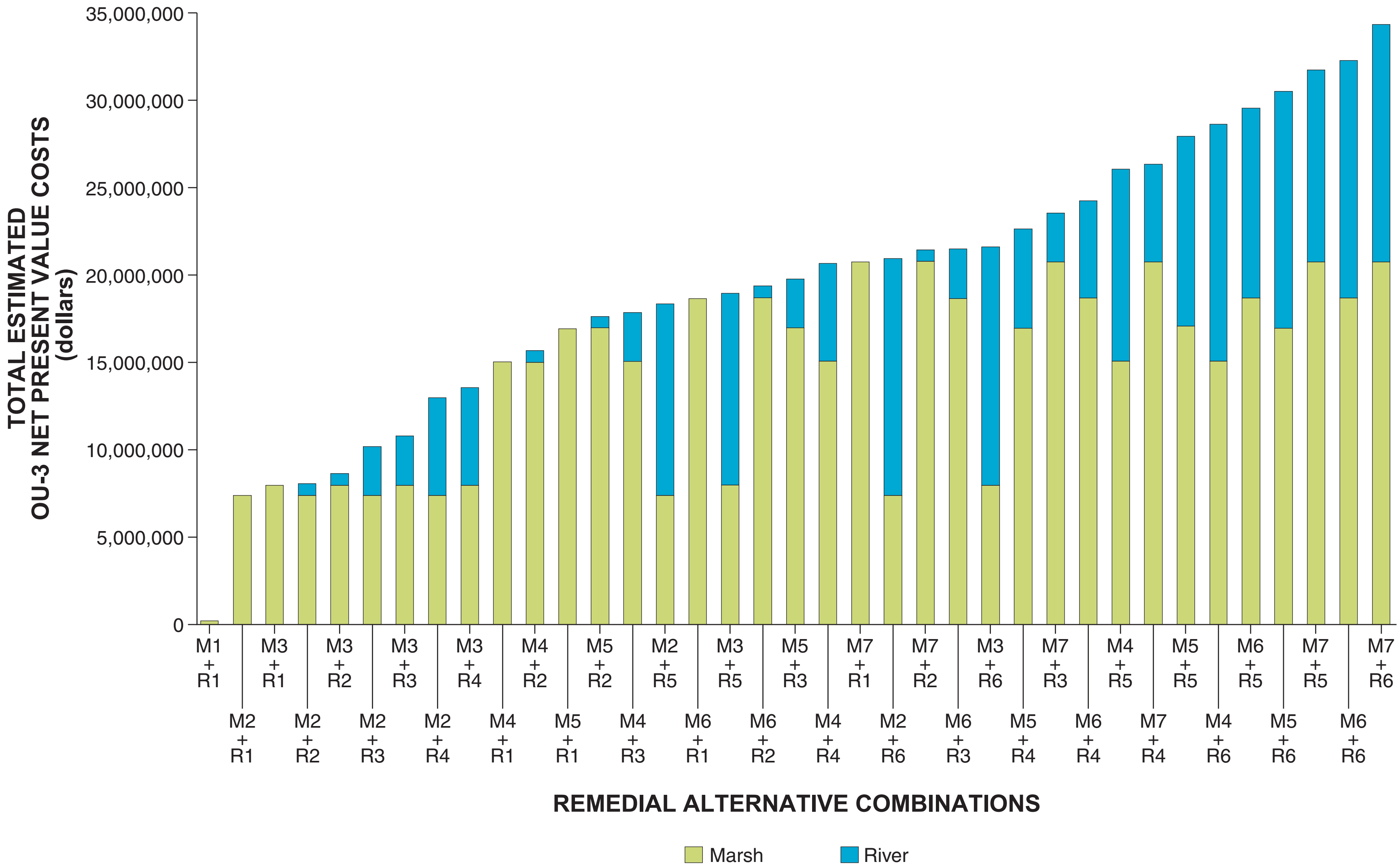


Figure 7-1. Cost range for marsh and river remedial alternatives

BE02578.001 1104 02/28/08 WA

Tables

Table 2-1. Preliminary remediation goals for marsh sediment

Site-Specific Receptor	Arsenic (mg/kg)	Mercury (mg/kg)	Source
Human health (trespassers)	2,000	[a]	CDM (1999c)
Blackworm (biomass reduction)	32	3.6	Exponent (2006a)
Earthworm (biomass reduction)	1,050	15.5	Exponent (2006a)
Blackworm (survival)	17,800	68	Exponent (2006a)
Earthworm (survival)	17,800	68	Exponent (2006a)
Muskrat	183	24	See Appendix B
Marsh Wren	1,470	8.86	See Appendix B
Burrowing animals[b]	160	--	Prince (2007a, pers. comm.)
Benthic organisms[b]	--	2.0	Prince (2007a, pers. comm.)

Note: -- - not provided

[a] Mercury did not contribute significantly to risk to trespassers.

[b] EPA (Prince 2007a, pers. comm.) provided PRGs of 160 mg/kg arsenic for subsurface sediment to protect burrowing animals and 2 mg/kg mercury in surface sediment to protect benthic organisms from direct toxicity and other organisms from bioaccumulation. The 2 mg/kg mercury value is NJDEP's screening value for freshwater sediment (NJDEP 1998) and is based on the Persaud et al. (1993) review of sediment toxicity to benthic organisms. Both values were also selected by EPA to reduce releases to the Raritan River.

Table 2-2. Preliminary remediation goals for river sediment

Site-Specific Receptor	Arsenic (mg/kg)	Mercury (mg/kg)	Source
Human health (trespassers)	2,000	[a]	CDM (1999c)
Benthic organisms (survival)	194	2.6	CDM (2002b)
None[b]	100	--	Prince (2007a, pers. comm.)
None[b]	--	2.0	Prince (2007a, pers. comm.)

Note: -- - not provided

[a] Mercury did not contribute significantly to risk to trespassers.

[b] EPA (Prince 2007a, pers. comm.) provided PRGs of 100 mg/kg arsenic as the maximum river reference concentration and 2 mg/kg mercury in surface sediment to protect benthic organisms from direct toxicity and other organisms from bioaccumulation. The 2 mg/kg mercury value is NJDEP's screening value for freshwater sediment (NJDEP 1998) and is based on the Persaud et al. (1993) review of sediment toxicity to benthic organisms. The maximum river reference concentration for mercury is 3.9 mg/kg (Exponent 2006a,b).

Table 3-1. Screening of appropriate technologies for marsh sediments (retained technologies are boldfaced)

General Response Action	Remedial Technology	Process Options	Description	Effectiveness	Implementability	Cost	Retained (Yes/No) and Rationale for Not Retaining
I. No Action	**None**		**No action is performed at the site.**	**not effective**	**easily implemented**	**low**	**yes**
II. Institutional and Engineering Controls		**1. Fencing or other deterrents**	**Physical barriers or other deterrents to prevent or minimize potential exposure.**	**effective**	**implementable**	**low**	**yes**
		2. Deed restrictions or other legal controls	**Legal controls to prevent or minimize potential exposure. Generally applicable to human health exposure.**	**effective**	**implementable**	**low**	**yes**
III. Containment	**A. Capping**	**1. Thin sand/ sediment cover**	**Uses a thin layer of material to reduce surface concentrations and thereby reduce exposure to contaminated materials.**	**effective**	**implementable**	**moderate**	**yes**
		2. Thick sand/clay/gravel cap	Uses a layer of material as a barrier to limit exposure to, and prevent erosion of, contaminated materials.	effective	not administratively implementable due to restrictions on filling wetlands	moderate	no - not implementable
IV. *In Situ* Treatment	**A. Monitored Natural Recovery**		**Uses natural processes such as degradation and burial by sediment deposition, along with monitoring.**	**potentially effective depending on sediment-ation rate**	**easily implemented**	**low**	**yes**
	B. Immobilization	1. Chemical fixation	Chemical reactions are induced between a stabilizing agent and contaminants to reduce contaminant mobility.	not effective for low-level threat wastes[a]	implementable	high	no - not effective
	C. Electrokinetic Separation		Uses low intensity direct current applied through electrodes to mobilize and remove metals and polar organic contaminants from low permeability soil and sediment.	not effective for low-level threat wastes[a]	implementable	high	no - not effective
V. Removal	**B. Excavation**	**1. Front-end loader**	**Uses front bucket for excavation. Could possibly be used for limited excavation of marsh sediments.**	**effective**	**implementable**	**moderate**	**yes**

Table 3-1. (cont.)

General Response Action	Remedial Technology	Process Options	Description	Effectiveness	Implementability	Cost	Retained (Yes/No) and Rationale for Not Retaining
		2. Drag-line	Excavates by means of a scoop bucket that is suspended from a long boom. The dragline digs by pulling the bucket toward the machine with a wire rope.	effective	implementable	high	no - higher cost than front end loader
		3. Scraper	Excavates by scraping material into a hopper. Could possibly be used for limited excavation of marsh sediments.	effective	not technically implementable due to shallow groundwater	moderate	no - not implementable
		4. Bulldozer	**Excavates by scraping and pushing material into piles. Could possibly be used for limited excavation of marsh sediments.**	**effective**	**implementable**	**moderate**	**yes**
	C. Phytoremediation	1. Phytoaccum-ulation	Uses plants to take up contaminants from soil or sediment and accumulate them in shoots or leaves. Could possibly be applied to marsh sediments.	not effective for low-level threat wastes[a]	implementable	low	no - not effective
		2. Phytostabiliza-tion	Uses plants that produce chemical compounds to immobilize contaminants at the interface of roots and soil. Could possibly be applied to marsh sediments.	not effective for low-level threat wastes[a]	implementable	low	no - not effective
VI. *Ex Situ* Treatment	**A. Dewatering**		**Removes excess water from excavated or dredged sediment to facilitate other treatment or disposal options.**	**effective if required for disposal**	**implementable**	**low**	**yes**
	B. Physical Separation	1. Screening	Uses physical screening to separate different size fractions from the sediment.	not effective for fine soils present at site	implementable	low	no - not effective
		2. Sediment washing	Contaminants sorbed onto fine soil particles are separated from bulk sediment on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.	not effective for fine soils present at site	implementable	high	no - not effective
		3. Centrifugal separation	Uses a vortex to generate centrifugal force, for density-based separation.	not effective for fine soils present at site	implementable	high	no - not effective

Table 3-1. (cont.)

General Response Action	Remedial Technology	Process Options	Description	Effectiveness	Implementability	Cost	Retained (Yes/No) and Rationale for Not Retaining
	C. Electrokinetic Separation		Uses low intensity direct current applied through electrodes to mobilize and remove metals and polar organic contaminants from low permeability soil and sediment.	not effective for low-level threat wastes[a]	implementable	high	no - not effective
	D. Chemical Extraction	1. Acid extraction	Contaminated sediment and an acid extractant are mixed in an extractor, thereby dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.	not effective for low-level threat wastes[a]	implementable	high	no - not effective
		2. Solvent extraction	Contaminated sediment and a solvent extractant are mixed in an extractor, thereby dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.	not effective for low-level threat wastes[a]	implementable	high	no - not effective
	E. Thermal Treatment	1. Thermal desorption	Low temperature process (300-600°C) used to volatilize organic contaminants, which are captured and processed in an offgas treatment system.	not effective for metals[b]	implementable	high	no - not effective
		2. Incineration	High temperature process (870-1,200°C) used to combust (in the presence of oxygen) organic contaminants.	not effective for metals[b]	implementable	high	no - not effective
		3. Pyrolysis	A process used to chemically decompose organic contaminants, conducted in the absence of oxygen, typically under pressure, and at temperatures >430°C.	not effective for metals[b]	implementable	high	no - not effective
	B. Immobilization	1. Chemical fixation	Chemical reactions are induced between a stabilizing agent and contaminants to reduce contaminant mobility.	not effective for low-level threat wastes[a]	implementable	moderate	no - not effective
VII. Disposal	**B. Onshore/ Upland Disposal**	**1. Onsite landfill**	**Dredged or excavated contaminated sediment is placed as an onshore fill and capped.**	**effective**	**implementable**	**moderate**	**yes**

Table 3-1. (cont.)

General Response Action	Remedial Technology	Process Options	Description	Effectiveness	Implementability	Cost	Retained (Yes/No) and Rationale for Not Retaining
		2. Regional landfill	**Dredged or excavated contaminated sediment is transported to a regional landfill for disposal. May be combined with an ex situ treatment technology to meet disposal requirements.**	**effective**	**implementable**	**moderate**	**yes**

Note: Bolded technologies were retained for assembly of remedial alternatives.

[a] EPA's presumptive remedy for metals-in-soil sites identifies the technologies that are applicable to principal-threat wastes and low-level threat wastes. Confinement is the presumptive remedy for low-threat-level wastes (U.S. EPA 1999).

[b] Not effective for metals other than mercury.

Table 3-2. Screening of appropriate technologies for nearshore river sediments (retained technologies are boldfaced)

General Response Action	Remedial Technology	Process Options	Description	Effectiveness	Implementability	Cost	Retained (Yes/No) and Rationale for Not Retaining
I. No Action	**None**		**No action is performed at the site.**	**not effective**	**easily implemented**	**low**	**yes**
II. Institutional and Engineering Controls	**Deed restrictions or other legal controls**		**Legal controls to prevent or minimize potential exposure. Generally applicable to human health exposure.**	**effective**	**implementable**	**low**	**yes**
III. Containment	**A. Capping**	**1. Thin sand/ sediment cap**	**Uses a thin layer of material to reduce surface concentrations and thereby reduce exposure to contaminated materials.**	**effective**	**implementable**	**low**	**yes**
		2. Thick sand/ clay/gravel cap	**Uses a layer of material as a barrier to limit exposure to, and prevent erosion of, contaminated materials.**	**effective**	**implementable**	**moderate**	**yes**
IV. *In Situ* Treatment	**A. Monitored natural recovery**		**Uses natural processes such as degradation and burial by sediment deposition, along with monitoring.**	**potentially effective, depending on sedimentation rate**	**easily implemented**	**low**	**yes**
	B. Immobilization	1. Chemical fixation	Chemical reactions are induced between a stabilizing agent and contaminants to reduce contaminant mobility.	not effective for low-level threat wastes[a]	not technically implementable	moderate	no - not effective nor technically implementable
	C. Electrokinetic separation		Uses low intensity direct current applied through electrodes to mobilize and remove metals and polar organic contaminants from low permeability soil and sediment.	not effective for low-level threat wastes[a]	not technically implementable	high	no - not effective nor technically implementable
V. Removal	**A. Dredging**	**1. Mechanical**	**Uses equipment such as a clamshell bucket to remove sediment.**	**effective**	**implementable**	**moderate**	**yes**
		2. Hydraulic	Uses centrifugal pumps to remove and transport sediment and water via a pipeline to a barge or disposal facility.	effective	implementable	high	no - mechanical dredging is considered to be lower cost

Table 3-2. (cont.)

General Response Action	Remedial Technology	Process Options	Description	Effectiveness	Implementability	Cost	Retained (Yes/No) and Rationale for Not Retaining
VI. *Ex Situ* Treatment	**A. Dewatering**		**Removes excess water from excavated or dredged sediment to facilitate other treatment or disposal options.**	**effective**	**implementable**	**low**	**yes**
	B. Physical separation	1. Screening	Uses physical screening to separate different size fractions from the sediment.	not effective for fine sediments present at site	implementable	low	no - not effective
		2. Sediment washing	Contaminants sorbed onto fine soil particles are separated from bulk sediment on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.	not effective for fine sediments present at site	implementable	moderate	no - not effective
		3. Centrifugal separation	Uses a vortex to generate centrifugal force, for density-based separation.	not effective for fine sediments present at site	implementable	high	no - not effective
	C. Electrokinetic separation		Uses low intensity direct current applied through electrodes to mobilize and remove metals and polar organic contaminants from low permeability soil and sediment.	not effective for low-level threat wastes[a]	implementable	high	no - not effective
	D. Chemical extraction	1. Acid extraction	Contaminated sediment and an acid extractant are mixed in an extractor, thereby dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.	not effective for low-level threat wastes[a]	implementable	high	no - not effective
		2. Solvent extraction	Contaminated sediment and a solvent extractant are mixed in an extractor, thereby dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.	not effective for low-level threat wastes[a]	implementable	high	no - not effective

Table 3-2. (cont.)

General Response Action	Remedial Technology	Process Options	Description	Effectiveness	Implementability	Cost	Retained (Yes/No) and Rationale for Not Retaining
	E. Thermal Treatment	1. Thermal desorption	Low temperature process (300–600°C) used to volatilize organic contaminants, which are captured and processed in an offgas treatment system.	not effective for metals	implementable	high	no - not effective
		2. Incineration	High temperature process (870–1,200°C) used to combust (in the presence of oxygen) organic contaminants.	not effective for metals	implementable	high	no - not effective
		3. Pyrolysis	A process used to chemically decompose organic contaminants, conducted in the absence of oxygen, typically under pressure, and at temperatures >430°C.	not effective for metals	implementable	high	no - not effective
	F. Immobilization	1. Chemical fixation	Uses cementitious materials to solidify the contaminated sediment, immobilizing the contaminants within the matrix.	not effective for low-level threat wastes[a]	implementable	moderate	no - not effective
VII. Disposal	A. Confined aquatic disposal		Dredged contaminated sediment is placed in an aquatic disposal site and capped.	effective	implementable but administratively more difficult than other disposal options	moderate	no - administratively more difficult
	B. Onshore/upland disposal	**1. Onsite landfill**	**Dredged or excavated contaminated sediment is placed as an onshore fill and capped.**	**effective**	**implementable**	**moderate**	**yes**
		2. Regional landfill	**Dredged or excavated contaminated sediment is transported to a regional landfill for disposal. May be combined with an ex situ treatment technology to meet disposal requirements.**	**effective**	**implementable**	**moderate**	**yes**

Note: Bolded technologies were retained for assembly of remedial alternatives.

[a] EPA's presumptive remedy for metals-in-soil sites identifies the technologies that are applicable to principal-threat wastes and low-level threat wastes. Confinement is the presumptive remedy for low-threat-level wastes (U.S. EPA 1999).

Table 3-3. Remedial alternatives for Horseshoe Rd/ARC OU-3 marsh and river sediments

	Remedial Alternative
Marsh	
	Alternative M1—No Action
	Alternative M2—Channel Excavation, Thin Cover, and Monitored Natural Recovery
	Alternative M3—Surficial Hot Spot Removal and Monitored Natural Recovery
	Alternative M4—Shallow Hot Spot Removal and Thin Cover
	Alternative M5—Extended Shallow Removal and Thin Cover
	Alternative M6—Extended Deep Removal and Thin Cover
	Alternative M7—Complete Removal
River	
	Alternative R1—No Action
	Alternative R2—Monitored Natural Recovery
	Alternative R3—Shallow Dredge and Thin Cap
	Alternative R4—Extended Shallow Dredge
	Alternative R5—Deep Dredge and Monitored Natural Recovery
	Alternative R6—Deep Dredge and Cover

Table 4-1. Comparison of marsh remedial alternatives to RAOs and PRGs

	Alternative M1–No Action	Alternative M2–Channel Excavation, Thin Cover, and Monitored Natural Recovery[a]	Alternative M3–Surficial Hot Spot Removal and Monitored Natural Recovery[a]	Alternative M4–Shallow Hot Spot Removal and Thin Cover	Alternative M5–Extended Shallow Removal and Thin Cover	Alternative M6—Extended Deep Removal and Thin Cover	Alternative M7—Complete Removal	Receptors or Basis for PRG
Marsh RAOs and PRGs								
RAO1—Reduce human health risks to acceptable levels	No	Yes	Yes	Yes	Yes	Yes	Yes	
PRG = 2,000 mg/kg arsenic	O	X	X	X	X	X	X	Area residents (trespassers)
RAO2—Reduce environmental risks to acceptable levels	No	Yes	Yes	Yes	Yes	Yes	Yes	
PRG = 32 mg/kg arsenic or 3.6 mg/kg mercury	O	X	X	X	X	X	X	Aquatic invertebrate biomass reduction
PRG = 160 mg/kg arsenic or 2.0 mg/kg mercury	O	X	X	X	X	X	X	Burrowing animals (for arsenic) and benthic organisms (direct toxicity and bioaccumulation for mercury)
PRG = 183 mg/kg arsenic or 24 mg/kg mercury	O	X	X	X	X	X	X	Plant-eating mammals
PRG = 1,050 mg/kg arsenic or 15.5 mg/kg mercury	O	X	X	X	X	X	X	Terrestrial invertebrate biomass reduction
PRG = 1,470 mg/kg arsenic or 8.86 mg/kg mercury	O	X	X	X	X	X	X	Insect-eating birds
PRG = 17,800 arsenic or 68 mg/kg mercury	O	X	X	X	X	X	X	Aquatic invertebrate survival and terrestrial invertebrate survival
RAO3—Minimize contaminant migration	No	Yes	Yes	Yes	Yes	Yes	Yes	
PRG = 160 mg/kg arsenic or 2.0 mg/kg mercury								

Note: PRG - preliminary remediation goal RAO - remedial action objective

[a] Effectiveness of monitored natural recovery is unproven for this site.

Table 4-2. Comparison of river remedial alternatives to RAOs and PRGs

	Alternative R1–No Action	Alternative R2–Monitored Natural Recovery[a]	Alternative R3–Shallow Dredge and Thin Cap	Alternative R4–Extended Shallow Dredge	Alternative R5–Deep Dredge and Monitored Natural Recovery	Alternative R6—Deep Dredge and Cover	Receptors or Basis for PRG
River RAOs and PRGs							
RAO4—Reduce human health risks within low tide mudflats	Yes[b]	Yes[b]	Yes	Yes	Yes	Yes	
PRG = 2,000 mg/kg arsenic	X[b]	X[b]	X	X	X	X	Area residents (trespassers)
RAO5—Reduce environmental risks to acceptable levels and minimize contaminant migration to the Raritan River Estuary	No	Yes	Yes	Yes	Yes	Yes	
PRG = 194 mg/kg arsenic or 2.6 mg/kg mercury	O	X	X	X	X	X	Benthic organism (survival)
PRG = 100 mg/kg arsenic or 2.0 mg/kg mercury	O	X	X	X	X	X	River reference (arsenic), NJDEP screening value (mercury)

Note: NJDEP - New Jersey Department of Environmental Protection
PRG - preliminary remediation goal
RAO - remedial action objective

[a] Effectiveness of monitored natural recovery is unproven for this site.

[b] Relies on implementation of an active remedy for the marsh.

Table 5-1. Detailed evaluation criteria

Threshold Criteria	
	Overall Protection of Human Health and the Environment
	Compliance with ARARs
Balancing Criteria	
	Long-term Effectiveness and Permanence
	Reduction of Toxicity, Mobility, or Volume through Treatment
	Short-term Effectiveness
	Implementability
	Cost
Modifying Criteria	
	State Acceptance
	Community Acceptance

Table 5-2. Analysis of Alternative M1—No action

Evaluation Criteria	Evaluation	
Overall Protection of Human Health and the Environment	The no action alternative will not be protective of human health and the environment. Existing contaminant exposure pathways to humans, aquatic and terrestrial invertebrates, and wildlife will remain unchanged, resulting in the potential for adverse effects to receptors. In addition, portions of the marsh will continue to act as a source of contaminants to the river.	
Compliance with ARARs	No short- or long-term exceedances of chemical-specific ARARs (e.g., water quality standards) are anticipated. Also, because no active remediation measures will be implemented, Alternative M1 is expected to comply with action-specific and location-specific ARARs.	
Long-term Effectiveness and Permanence	Does not provide significant long-term effectiveness. Conditions are expected to improve naturally over time; however, the rate of improvement is unknown and will not be verified because of lack of monitoring.	
Reduction of Toxicity, Mobility, or Volume through Treatment	No treatment will be performed, therefore, there will be no reduction of toxicity, mobility, or volume through treatment.	
Short-term Effectiveness	No remedial actions are associated with this alternative, so there will be no adverse impacts to the environment. The time required to achieve the RAOs is unknown.	
Implementability	The no action alternative is very easy to implement. Other than the acquisition of compensatory wetlands property for mitigation, there are no activities that require administrative coordination or approval and there are no activities that rely on equipment, materials, or services.	
Cost	Capital Cost	$0
	Annual Operation and Maintenance Cost	$0
	Total Periodic Cost	$300,000
	Total Present Value	$100,000

Table 5-3. Analysis of Alternative M2—Channel excavation, thin cover, and monitored natural recovery[a]

Evaluation Criteria	Evaluation
Overall Protection of Human Health and the Environment	The SPD/ADC channel excavation will reduce the potential for offsite migration of contaminants in surface water discharges, and will reduce the potential spread of more highly contaminated sediments to less contaminated portions of the marsh. Covering the remaining highly contaminated and moderately contaminated sediments will further reduce exposure, and over time, MNR will reduce the remaining ecological risks to acceptable levels.
Compliance with ARARs	No long-term exceedances of chemical-specific ARARs (e.g., water quality standards) are anticipated. Short-term localized exceedances of surface water quality standards are possible with this alternative during channel excavation and restoration activities. Measures will be taken to meet potential chemical-specific ARARs to minimize surface water quality effects in accordance with the Clean Water Act and State of New Jersey Surface Water Quality Standards. Channel excavation, channel restoration, and thin covering activities will be conducted in a manner such that location-specific ARARs for 100-year floodplain and wetlands will be met. The State of New Jersey Freshwater Protection Act requires that permits be obtained for activities disturbing wetlands. For dewatering activities during excavation and for the offsite disposal of contaminated sediments, and covering, action-specific ARARs will have to be met. This will involve obtaining the appropriate permits (e.g., NPDES permits for construction activities) and complying with RCRA regulations for the transportation and disposal of hazardous waste. Alternative M2 will achieve compliance with ARARs and also TBC guidance from EPA concerning the presumptive remedy for metals-in-soil sites (U.S. EPA 1999).
Long-term Effectiveness and Permanence	Excavated contaminants from the SPD/ADC channel corridor will be permanently removed from the site and risks for adverse effects to invertebrates within this drainage channel will be eliminated. Contaminated sediments that are not removed will remain onsite indefinitely, but the residual risks are low. An effective cover along with MNR and site access restrictions will further limit human and ecological exposure, thereby minimizing the potential for long-term residual risk. Periodic site inspections and maintenance of the cover and site fencing will be necessary to reduce the potential for future exposure to the covered sediments.
Reduction of Toxicity, Mobility, or Volume through Treatment	Principal threat wastes do not exist within the OU-3 area and no treatment of excavated marsh sediments is anticipated. Therefore, there will be no reduction of toxicity, mobility, and volume through treatment.
Short-term Effectiveness	Environmental impacts will be expected for areas of the channel and marsh where channel excavation and covering activities occur and also to other areas affected by movement of machinery needed to perform remedial actions. These impacts will include temporary alteration of hydrological function of stream channels, short-term impairment of stream benthic and aquatic communities, and removal or compaction of marsh vegetation. Although these impacts will be severe, they will affect only a small area and recovery is expected to be rapid. Site controls such as security fencing, drainage diversion, sedimentation basins, and silt fencing will minimize potential impacts to the surrounding environment and the community. Workers will be exposed to contaminated sediments and water and also to physical hazards associated with heavy equipment construction activities. Adherence to an adequate health and safety plan will minimize these risks. RAOs within the excavated SPD/ADC drainage channel and covered areas will be achieved immediately upon completion of construction; estimated to take less than 3 months. RAOs in other areas of the marsh will be achieved in a longer period of time dependent on the rate of natural recovery. Recovery of the site ecological communities to pre-remediation conditions is expected to take no more than 2 years.

Table 5-3. (cont.)

Evaluation Criteria	Evaluation	
Implementability	This alternative is implementable. Although the removal and backfill/covering activities in the marsh and tidelands are challenging tasks, the equipment, materials, and skills needed to perform these actions are readily available. Similar actions have been implemented successfully at other sites with similar conditions. Compensatory wetlands acquisition as a result of topography changes and deed restrictions to control future site access and development are anticipated for this alternative. These will require a moderate amount of effort but are considered to be administratively feasible.	
Cost (See detailed cost estimate in Appendix E.)	Capital Cost Annual Operation and Maintenance Cost Total Periodic Cost Total Present Value	\$7,100,000 \$1,700 \$550,000 \$7,400,000

[a] Effectiveness of monitored natural recovery is unproven for this site.

Table 5-4. Analysis of Alternative M3—Surficial hot spot removal and monitored natural recovery[a]

Evaluation Criteria	Evaluation
Overall Protection of Human Health and the Environment	SPD/ADC channel excavation and restoration will reduce human health risks to acceptable levels (i.e., hazard index < 1.0) and will also eliminate risks to invertebrates and wildlife within the channel corridor. SPD/ADC channel excavation and restoration and surficial hot spot removal and backfilling will also reduce the potential for offsite migration of contaminants in surface water discharges, and will reduce the potential spread of more highly contaminated sediments to less contaminated portions of the marsh. Over time, MNR will reduce contaminant concentrations in other portions of the marsh.
Compliance with ARARs	No long-term exceedances of chemical-specific ARARs (e.g., water quality standards) are anticipated. Short-term localized exceedances of surface water quality standards are possible with this alternative during excavation and backfilling activities. Measures will be taken to meet potential chemical-specific ARARs to minimize surface water quality effects in accordance with the Clean Water Act and State of New Jersey Surface Water Quality Standards. Excavation and backfilling activities will be conducted in a manner such that location-specific ARARs for 100-year floodplain and wetlands will be met. The State of New Jersey Freshwater Protection Act requires that permits be obtained for activities disturbing wetlands. For dewatering activities during excavation and for the offsite disposal of contaminated sediments, action-specific ARARs will have to be met. This will involve obtaining the appropriate permits (e.g., NPDES permits for construction activities) and complying with RCRA regulations for the transportation and disposal of hazardous waste. Alternative M3 will achieve compliance with ARARs and also TBC guidance from EPA concerning the presumptive remedy for metals-in-soil sites (U.S. EPA 1999).
Long-term Effectiveness and Permanence	Excavated contaminants from the SPD/ADC channel corridor and surficial hot spots will be permanently removed from the site and risks for adverse effects to invertebrates within this drainage channel will be eliminated. Contaminated sediments that are not removed will remain onsite indefinitely, but the residual risks are low. An effective backfill/cover over the remaining higher contaminated sediments along with MNR and site access restrictions will further limit human and ecological exposure, thereby minimizing the potential for long-term residual risk. Periodic site inspections and maintenance of the cover and site fencing will be necessary to reduce the potential for future exposure. Site monitoring and periodic reviews will provide adequate control until the RAOs are met.
Reduction of Toxicity, Mobility, or Volume through Treatment	Principal threat wastes do not exist within the OU-3 area and no treatment of excavated marsh sediments is anticipated. Therefore, there will be no reduction of TMV through treatment.
Short-term Effectiveness	Environmental impacts are expected for areas of the SPD/ADC channel and marsh where hot spot removal actions occur and also for other areas affected by movement of machinery needed to perform remedial actions. These impacts will include temporary alteration of hydrological function of stream channels, short-term impairment of stream benthic and aquatic communities, and removal or compaction of marsh vegetation. Recovery is expected to be rapid. Site controls such as security fencing, drainage diversion, sedimentation basins, and silt fencing will minimize potential impacts to the surrounding environment and the community. Workers will be exposed to contaminated sediments and water and also to physical hazards associated with heavy equipment construction activities. Adherence to an adequate health and safety plan will minimize these risks. RAOs within the excavated drainage channels and hot spot areas will be achieved immediately upon completion of construction; estimated to take less than 3 months. RAOs in other areas of the marsh will be achieved in a longer period of time dependent on the rate of natural recovery.

Table 5-4. (cont.)

Evaluation Criteria	Evaluation	
Implementability	This alternative is implementable. Although the removal activities in the marsh and tidelands are challenging tasks, the equipment, materials, and skills needed to perform these actions are readily available. Similar actions have been implemented successfully at other sites with similar conditions.	
Cost (See detailed cost estimate in Appendix E.)	Capital Cost Annual Operation and Maintenance Cost Total Periodic Cost Total Present Value	\$7,670,000 \$1,700 \$550,000 \$8,000,000

[a] Effectiveness of monitored natural recovery is unproven for this site.

Table 5-5. Analysis of Alternative M4—Shallow hot spot removal and thin cover

Evaluation Criteria	Evaluation
Overall Protection of Human Health and the Environment	SPD/ADC channel excavation and restoration will reduce human health risks to acceptable levels (i.e., hazard index < 1.0) and will also eliminate risks to invertebrates and wildlife within the channel corridor. SPD/ADC channel excavation and restoration and shallow hot spot removal and backfilling will also reduce the potential for offsite migration of contaminants in surface water discharges, and will reduce the potential spread of more highly contaminated sediments to less contaminated portions of the marsh. Covering the remaining sediments that exceed the marsh PRGs will further reduce the remaining ecological risks to acceptable levels.
Compliance with ARARs	No long-term exceedances of chemical-specific ARARs (e.g., water quality standards) are anticipated. Short-term localized exceedances of surface water quality standards are possible with this alternative during excavation and backfilling/covering activities. Measures will be taken to meet potential chemical-specific ARARs to minimize surface water quality effects in accordance with the Clean Water Act and State of New Jersey Surface Water Quality Standards. Excavation, backfilling, and covering activities will be conducted in a manner such that location-specific ARARs for 100-year floodplain and wetlands will be met. The State of New Jersey Freshwater Protection Act requires that permits be obtained for activities disturbing wetlands. For dewatering activities during excavation and for the offsite disposal of contaminated sediments, action-specific ARARs will have to be met. This will involve obtaining the appropriate permits (e.g., NPDES permits for construction activities) and complying with RCRA regulations for the transportation and disposal of hazardous waste. Alternative M4 will achieve compliance with ARARs and also TBC guidance from EPA concerning the presumptive remedy for metals-in-soil sites (U.S. EPA 1999).
Long-term Effectiveness and Permanence	Excavation and offsite disposal of sediments will permanently remove contaminants from the SPD/ADC drainage channel and hot spot areas. Risks for adverse effects to invertebrates within excavated areas will be greatly reduced or eliminated. Contaminated sediments that are not removed will remain onsite indefinitely, but the residual risks are low and an effective cover will limit human and ecological exposure, thereby minimizing the potential for long-term residual risk. Periodic site inspections and maintenance of the cover will be necessary to reduce the potential for future exposure to the covered sediments. Site monitoring and periodic reviews will provide adequate control until the RAOs are met.
Reduction of Toxicity, Mobility, or Volume through Treatment	Principal threat wastes do not exist within the OU-3 area and no treatment of excavated marsh sediments is anticipated. Therefore, there will be no reduction of toxicity, mobility, and volume through treatment.
Short-term Effectiveness	Environmental impacts are expected for areas of the SPD/ADC drainage channel and marsh where excavation and backfilling occur. These impacts will include temporary alteration of hydrological function of stream channels, short-term impairment of stream benthic and aquatic communities, and complete removal of marsh vegetation and loss of wildlife habitat. Recovery from these onsite impacts is expected to be rapid. Site controls such as security fencing, drainage diversion, sedimentation basins, and silt fencing will minimize potential impacts to the surrounding environment and the community. Workers will be exposed to contaminated sediments and water and also to physical hazards associated with heavy equipment construction activities. Adherence to an adequate health and safety plan will minimize these risks. All RAOs will be attained upon completion of implementation of the remedial measures, estimated to take approximately 3 months. Recovery of the site ecological communities to pre-remediation conditions is expected to take no more than 2 years.

Table 5-5. (cont.)

Evaluation Criteria	Evaluation	
Implementability	This alternative is implementable. Although the removal and covering activities in the marsh and tidelands are challenging tasks, the equipment, materials, and skills needed to perform these actions are readily available. Similar actions have been implemented successfully at other sites with similar conditions. Compensatory wetlands acquisition as a result of topography changes is anticipated for this alternative. This will require a moderate amount of effort but are considered to be administratively feasible.	
Cost (See detailed cost estimate in Appendix E.)	Capital Cost Annual Operation and Maintenance Cost Total Periodic Cost Total Present Value	$14,710,000 $1,700 $550,000 $15,000,000

Table 5-6. Analysis of Alternative M5—Extended shallow removal and thin cover

Evaluation Criteria	Evaluation
Overall Protection of Human Health and the Environment	SPD/ADC channel excavation and restoration will reduce human health risks to acceptable levels (i.e., hazard index < 1.0) and will also eliminate risks to invertebrates and wildlife within the channel corridor. SPD/ADC channel excavation and restoration and shallow removal and backfilling of the highly contaminated and moderately contaminated areas will also reduce the potential for offsite migration of contaminants in surface water discharges, and will reduce the potential spread of more highly contaminated sediments to less contaminated portions of the marsh. Covering the remaining sediments that exceed the marsh PRGs will further reduce the remaining ecological risks to acceptable levels.
Compliance with ARARs	No long-term exceedances of chemical-specific ARARs (e.g., water quality standards) are anticipated. Short-term localized exceedances of surface water quality standards are possible with this alternative during excavation activities. Measures will be taken to meet potential chemical-specific ARARs to minimize surface water quality effects in accordance with the Clean Water Act and State of New Jersey Surface Water Quality Standards. Excavation and backfilling/covering activities will be conducted in a manner such that location-specific ARARs for 100-year floodplain and wetlands will be met. The State of New Jersey Freshwater Protection Act requires that permits be obtained for activities disturbing wetlands. For dewatering activities during excavation and for the offsite disposal of contaminated sediments, action-specific ARARs will have to be met. This will involve obtaining the appropriate permits (e.g., NPDES permits for construction activities) and complying with RCRA regulations for the transportation and disposal of hazardous waste). Alternative M5 will achieve compliance with ARARs and also TBC guidance from EPA concerning the presumptive remedy for metals-in-soil sites (U.S. EPA 1999).
Long-term Effectiveness and Permanence	Excavation and offsite disposal of sediments will permanently remove contaminants from the SPD/ADC drainage channel and hot spot and moderately contaminated areas. Risks for adverse effects to invertebrates within excavated areas will be greatly reduced or eliminated. Contaminated sediments that are not removed will remain onsite indefinitely, but the residual risks are low and an effective cover will limit human and ecological exposure, thereby minimizing the potential for long-term residual risk. Periodic site inspections and maintenance of the cover will be necessary to reduce the potential for future exposure to the covered sediments. Site monitoring and periodic reviews will provide adequate control until the RAOs are met.
Reduction of Toxicity, Mobility, or Volume through Treatment	Principal threat wastes do not exist within the OU-3 area and no treatment of excavated marsh sediments is anticipated. Therefore, there will be no reduction of toxicity, mobility, or volume through treatment.
Short-term Effectiveness	Environmental impacts are expected for areas of the SPD/ADC channel and marsh where excavation and backfill/covering occur. These impacts will include temporary alteration of hydrological function of stream channels, short-term impairment of stream benthic and aquatic communities, and complete removal of marsh vegetation and loss of wildlife habitat. Recovery from these onsite impacts is expected to be rapid. Site controls such as security fencing, drainage diversion, sedimentation basins, and silt fencing will minimize potential impacts to the surrounding environment and the community. Workers will be exposed to contaminated sediments and water and also to physical hazards associated with heavy equipment construction activities. Adherence to an adequate health and safety plan will minimize these risks. All RAOs will be attained upon completion of the remedial measures, estimated to take less than 6 months. Recovery of the site ecological communities to pre-remediation conditions is expected to take no more than 2 years.

Table 5-6. (cont.)

Evaluation Criteria	Evaluation	
Implementability	This alternative is implementable. Although the removal and backfilling/covering activities in the marsh and tidelands are challenging tasks, the equipment, materials, and skills needed to perform these actions are readily available. Similar actions have been implemented successfully at other sites with similar conditions. Compensatory wetlands acquisition as a result of topography changes is anticipated for this alternative. This will require a moderate amount of effort but are considered to be administratively feasible.	
Cost (See detailed cost estimate in Appendix E.)	Capital Cost Annual Operation and Maintenance Cost Total Periodic Cost Total Present Value	\$16,600,000 \$1,700 \$450,000 \$16,900,000

Table 5-7. Analysis of Alternative M6—Extended deep removal and thin cover

Evaluation Criteria	Evaluation
Overall Protection of Human Health and the Environment	Extended deep removal excavation will provide overall protection of human health and invertebrates and wildlife in the marsh by removing virtually all of the hot spot and moderately contaminated sediment and disposing material offsite. In-channel and marsh excavation will greatly reduce the potential for offsite migration of contaminants in surface water discharges. Covering the remaining sediments that exceed the marsh PRGs will further reduce the remaining ecological risks to acceptable levels.
Compliance with ARARs	No long-term exceedances of chemical-specific ARARs (e.g., water quality standards) are anticipated. Short-term localized exceedances of surface water quality standards are possible with this alternative during excavation activities. Measures will be taken to meet potential chemical-specific ARARs to minimize surface water quality effects in accordance with the Clean Water Act and State of New Jersey Surface Water Quality Standards. Excavation, backfilling, and covering activities will be conducted in a manner such that location-specific ARARs for 100-year floodplain and wetlands will be met. The State of New Jersey Freshwater Protection Act requires that permits be obtained for activities disturbing wetlands. For dewatering activities during excavation and for the offsite disposal of contaminated sediments, action-specific ARARs will have to be met. This will involve obtaining the appropriate permits (e.g., NPDES permits for construction activities) and complying with RCRA regulations for the transportation and disposal of hazardous waste). Alternative M6 will achieve compliance with ARARs.
Long-term Effectiveness and Permanence	Excavation and offsite disposal of sediments will permanently remove contaminants from the SPD/ADC drainage channel and hot spot and moderately contaminated areas. Risks for adverse effects to invertebrates within excavated areas will be greatly reduced or eliminated. Contaminated sediments that are not removed will remain onsite indefinitely, but the residual risks are low and an effective cover will limit human and ecological exposure, thereby minimizing the potential for long-term residual risk. Periodic site inspections and maintenance of the cover will be necessary to reduce the potential for future exposure to the covered sediments. Site monitoring and periodic reviews will provide adequate control until the RAOs are met.
Reduction of Toxicity, Mobility, or Volume through Treatment	Principal threat wastes do not exist within the OU-3 area and no treatment of excavated marsh sediments is anticipated. Therefore, there will be no reduction of toxicity, mobility, or volume through treatment.
Short-term Effectiveness	Environmental impacts are expected for areas of the SPD/ADC drainage channel and marsh where excavation and backfill/covering occur. These impacts will include temporary alteration of hydrological function of stream channels, short-term impairment of stream benthic and aquatic communities, and complete removal of marsh vegetation and loss of wildlife habitat. Recovery from these onsite impacts is expected to be rapid. Site controls such as security fencing, drainage diversion, sedimentation basins, and silt fencing will minimize potential impacts to the surrounding environment and the community. Workers will be exposed to contaminated sediments and water and also to physical hazards associated with heavy equipment construction activities. Adherence to an adequate health and safety plan will minimize these risks. All RAOs will be attained upon completion of the remedial measures, estimated to take less than 6 months. Recovery of the site ecological communities to pre-remediation conditions is expected to take no more than 2 years.
Implementability	This alternative is implementable. Although the removal and backfilling/covering activities in the marsh and tidelands are challenging tasks, the equipment, materials, and skills needed to perform these actions are readily available. Similar actions have been implemented successfully at other sites with similar conditions. Compensatory wetlands acquisition as a result of topography changes is anticipated for this alternative. This will require a moderate amount of effort but are considered to be administratively feasible.

Table 5-7. (cont.)

Evaluation Criteria	Evaluation	
Cost (See detailed cost estimate in Appendix E.)	Capital Cost Annual Operation and Maintenance Cost Total Periodic Cost Total Present Value	$18,460,000 $1,700 $450,000 $18,600,000

Table 5-8. Analysis of Alternative M7—Complete removal

Evaluation Criteria	Evaluation	
Overall Protection of Human Health and the Environment	Complete removal will provide overall protection of human health and invertebrates and wildlife in the marsh by removing virtually all contaminated sediment and disposing material offsite. Complete excavation and site restoration will eliminate the potential for offsite migration of contaminants in surface water discharges.	
Compliance with ARARs	No long-term exceedances of chemical-specific ARARs (e.g., water quality standards) are anticipated. Short-term localized exceedances of surface water quality standards are possible with this alternative during excavation activities. Measures will be taken to meet potential chemical-specific ARARs to minimize surface water quality effects in accordance with the Clean Water Act and State of New Jersey Surface Water Quality Standards. Excavation and backfilling activities will be conducted in a manner such that location-specific ARARs for 100-year floodplain and wetlands will be met. The State of New Jersey Freshwater Protection Act requires that permits be obtained for activities disturbing wetlands. For dewatering activities during excavation and for the offsite disposal of contaminated sediments, action-specific ARARs will have to be met. This will involve obtaining the appropriate permits (e.g., NPDES permits for construction activities) and complying with RCRA regulations for the transportation and disposal of hazardous waste). Alternative M7 will achieve compliance with ARARs.	
Long-term Effectiveness and Permanence	Complete excavation and offsite disposal of contaminated sediments will permanently remove contaminants from the site. Risks for adverse effects to invertebrates and wildlife receptors within excavated areas will be eliminated. There will be no significant quantities of contaminated sediments at the site and no need for long-term maintenance or monitoring.	
Reduction of Toxicity, Mobility, or Volume through Treatment	Principal threat wastes do not exist within the OU-3 area and no treatment of excavated marsh sediments is anticipated. Therefore, there will be no reduction of toxicity, mobility, or volume through treatment.	
Short-term Effectiveness	Environmental impacts are expected for areas of the SPD/ADC drainage channel and marsh where excavation occurs. These impacts will include temporary alteration of hydrological function of stream channels, short-term impairment of stream benthic and aquatic communities, and complete removal of marsh vegetation and loss of wildlife habitat. Recovery from these onsite impacts is expected to be rapid. Site controls such as security fencing, drainage diversion, sedimentation basins, and silt fencing will minimize potential impacts to the surrounding environment and the community. Workers will be exposed to contaminated sediments and water and also to physical hazards associated with heavy equipment construction activities. Adherence to an adequate health and safety plan will minimize these risks. All RAOs will be attained upon completion of the remedial measures, estimated to take less than 6 months. Recovery of the site ecological communities to pre-remediation conditions are expected to take no more than 2 years.	
Implementability	This alternative is implementable. Although the removal and backfilling activities in the marsh and tidelands are challenging tasks, the equipment, materials, and skills needed to perform these actions are readily available. Similar actions have been implemented successfully at other sites with similar conditions.	
Cost (See detailed cost estimate in Appendix E.)	Capital Cost Annual Operation and Maintenance Cost Total Periodic Cost Total Present Value	$20,530,000 $1,700 $250,000 $20,700,000

Table 5-9. Analysis of Alternative R1—No action

Evaluation Criteria	Evaluation
Overall Protection of Human Health and the Environment	Human health risks have been identified for the river associated with a total noncarcinogenic hazard index greater than 1.0 (for trespassers), attributed to arsenic in sediment. The PRG to address this risk is 2,000 mg/kg arsenic which was exceeded at only one sampling station at the mouth of the SPD/ADC drainage channel. Because SPD/ADC drainage channel removal at this location was incorporated into all of the marsh remedial alternatives except the no action alternative, protection of human health risks is dependent on any remedial actions implemented for the marsh. Human health risks will remain in this portion of the Raritan River only if no action is selected for marsh remediation. The BERA did not identify risks associated with the site to fish, birds, or mammals in the river, and the SLERA addendum noted limited effects on benthic organisms only near the mouth of the SPD/ADC drainage. Therefore, risks to the environment and ecological receptors are considered to be minor under current conditions and are expected to remain so under this alternative.
Compliance with ARARs	No short-term or long-term exceedances of chemical-specific ARARs (e.g., water quality standards) are anticipated. Also, because no active remediation measures will be implemented, Alternative R1 is expected to comply with action-specific and location-specific ARARs.
Long-term Effectiveness and Permanence	Because there will be no remedial action conducted in the river, existing minor risks to human and ecological receptors are expected to remain unchanged. Conditions are expected to improve naturally over time; however, the rate of improvement is unknown and will not be verified because of lack of monitoring.
Reduction of Toxicity, Mobility, or Volume through Treatment	No treatment will be performed; therefore, there will be no reduction of toxicity, mobility, or volume through treatment.
Short-term Effectiveness	No remedial actions are associated with this alternative, so there will be no adverse impacts to the environment. The time required to achieve the remedial action objectives is unknown.
Implementability	The no action alternative is very easy to implement. There are no activities that require administrative coordination or approval and there are no activities that rely on equipment, materials, or services.
Cost (See detailed cost estimate in Appendix E.)	Capital Cost \$0 Annual Operation and Maintenance Cost \$0 Total Periodic Cost \$0 Total Present Value \$0

Table 5-10. Analysis of Alternative R2—Monitored natural recovery[a]

Evaluation Criteria	Evaluation	
Overall Protection of Human Health and the Environment	Although the only ecological risks identified for the OU-3 river sediments were limited effects on benthic organisms near the mouth of the SPD/ADC drainage, these would be reduced to acceptable levels over time by MNR. As discussed for Alternative R1, human health risks will remain in this portion of the Raritan River only if no action is selected for marsh remediation.	
Compliance with ARARs	No short- or long-term exceedances of chemical-specific ARARs (e.g., water quality standards) are anticipated. Also, because no intrusive remediation measures will be implemented, Alternative R2 is expected to comply with action-specific and location-specific ARARs.	
Long-term Effectiveness and Permanence	Existing minor risks to human and ecological receptors are expected to remain unchanged until upstream source control measures are implemented (e.g., in the SPD/ADC drainage). After upstream sources are controlled, conditions are expected to improve naturally. Site monitoring and periodic reviews will provide adequate control until all RAOs are met.	
Reduction of Toxicity, Mobility, or Volume through Treatment	No treatment will be performed; therefore, there will be no reduction of toxicity, mobility, or volume through treatment.	
Short-term Effectiveness	Environmental impacts to surrounding areas and populations during implementation of monitoring measures will be minimal and adherence to an appropriate health and safety plan should minimize risks to monitoring personnel. The time required to achieve the RAOs is dependent on the rate of natural recovery.	
Implementability	This alternative is easily implemented. The monitoring to be conducted has been performed at other similar sites and the required equipment and expertise is readily available. No approvals are necessary other than from EPA and NJDEP.	
Cost (See detailed cost estimate in Appendix E.)	Capital Cost Annual Operation and Maintenance Cost Total Periodic Cost Total Present Value	\$240,000 \$0 \$820,000 \$670,000

[a] Effectiveness of monitored natural recovery is unproven for this site.

Table 5-11. Analysis of Alternative R3—Shallow dredge and thin cap

Evaluation Criteria	Evaluation
Overall Protection of Human Health and the Environment	Although the only ecological risks identified for the OU-3 River sediments were limited effects on benthic organisms near the mouth of the SPD/ADC drainage, these would be reduced by shallow dredging and placement of a thin cap. In addition, the thin cap will reduce the potential for exposure to contaminant concentrations in excess of ambient Raritan River conditions. Assuming that continuing contributions of contaminants are eliminated by implementation of any of the marsh remedial alternatives other than no action, human health risks will be within acceptable levels.
Compliance with ARARs	No long-term exceedances of chemical-specific ARARs (e.g., water quality standards) are anticipated. Short-term localized exceedances of surface water quality standards are possible with this alternative during dredging and capping activities. Measures will be taken to meet potential chemical-specific ARARs to minimize surface water quality effects during dredging activities, in accordance with the Clean Water Act and State of New Jersey Surface Water Quality Standards. Dredging and capping activities will be conducted in a manner such that location-specific ARARs, such as the U.S. Rivers and Harbors Act and the Waterfront Development Act, will be met, and appropriate State of New Jersey permits for dredging and capping activities on the waterfront will be obtained. For the potential offsite disposal of contaminated sediments, action-specific ARARs will have to be met. This will involve obtaining the appropriate permits (e.g., NPDES permits for the treatment and return discharge of Raritan River water generated during dredging) and compliance with RCRA regulations for the transportation and disposal of solid waste. Alternative R3 will achieve compliance with ARARs.
Long-term Effectiveness and Permanence	Contaminants in the dredged sediments will be permanently removed from the site and risks for adverse effects to human and ecological receptors within the dredged areas will be eliminated. There will be minor quantities of residual contaminants beneath the backfill and also outside the dredging areas. The long-term effectiveness of the cap is dependent on the scour velocities likely to be encountered and the susceptibility of the cap material to erosion. Preliminary analysis of these conditions for a 100-year frequency flood at the site (see Appendix C) indicates that flow velocities are unlikely to erode the capping material. Residual risks at the site are considered negligible. If upstream source areas (e.g., the SPD/ADC drainage) have not been controlled there will be a risk for recontamination of the remediated OU-3 river sediments. Regional monitoring performed to assess Raritan River Estuary quality will provide adequate control to ensure that recontamination does not occur. Site-specific monitoring of cap integrity and periodic (5-year) review of conditions at the Horseshoe Road site should provide adequate control to ensure that long-term performance of the remedy is effective.
Reduction of Toxicity, Mobility, or Volume through Treatment	No treatment will be performed therefore there will be no reduction of toxicity, mobility, or volume through treatment.
Short-term Effectiveness	Dredging and capping will result in short-term disruption of benthic invertebrate communities with indirect food-chain effects until recolonization and recovery of the benthic community occurs. Recovery is expected to be rapid. All RAOs will be attained upon completion of dredging and backfilling remedial actions and cap placement, estimated to take approximately 1 to 2 months. Recovery of the site ecological communities to pre-remediation conditions is expected to take no more than 2 years.
Implementability	The shallow conditions in this area present problems for mobilizing equipment and materials by barge and will likely require intermittent activity dictated by tidal fluctuations. This will decrease the dredging and capping application rates, but does not otherwise represent an insurmountable problem. Materials, equipment, and application expertise are readily available and the technology is reliable. Similar actions have been implemented successfully at other sites with similar conditions. The increased bed elevation caused by thin cap placement may be unacceptable to the permitting authorities and, if so, this alternative will be administratively infeasible.

Table 5-11. (cont.)

Evaluation Criteria	Evaluation	
Cost (See detailed cost estimate in Appendix E.)	Capital Cost Annual Operation and Maintenance Cost Total Periodic Cost Total Present Value	$2,620,000 $0 $820,000 $2,800,000

Table 5-12. Analysis of Alternative R4—Extended shallow dredge

Evaluation Criteria	Evaluation
Overall Protection of Human Health and the Environment	Although the only ecological risks identified for the OU-3 River sediments were limited effects on benthic organisms near the mouth of the SPD/ADC drainage, these will be reduced by the shallow removal and replacement of this material. In addition, this action will reduce the potential for exposure to contaminant concentrations in excess of ambient Raritan River conditions Human health risks will be reduced to acceptable levels either by removal under one of the OU-3 Marsh remedial alternatives or by removal under this alternative.
Compliance with ARARs	No long-term exceedances of chemical-specific ARARs (e.g., water quality standards) are anticipated. Short-term localized exceedances of surface water quality standards are possible with this alternative during dredging and backfilling activities. Measures would be taken to meet potential chemical-specific ARARs to minimize surface water quality effects in accordance with the Clean Water Act and State of New Jersey Surface Water Quality Standards. Dredging and backfill activities would be conducted in a manner such that location-specific ARARs, such as the U.S. Rivers and Harbors Act and the Waterfront Development Act, will be met, and appropriate State of New Jersey permits for dredging activities on the waterfront will be obtained. For the potential offsite disposal of contaminated sediments, action-specific ARARs will have to be met. This will involve obtaining the appropriate permits (e.g., NPDES permits for the treatment and return discharge of Raritan River water generated during dredging) and compliance with RCRA regulations for the transportation and disposal of solid waste. Alternative R4 will achieve compliance with ARARs.
Long-term Effectiveness and Permanence	Contaminants in the dredged sediments will be permanently removed from the site and risks for adverse effects to human and ecological receptors within the dredged areas will be eliminated. There will be minor quantities of residual contaminants beneath the backfill and also outside the dredging areas. The long-term effectiveness of dredging and backfilling is dependent on the scour velocities likely to be encountered and the susceptibility of the backfilled material to erosion. Preliminary analysis of these conditions for a 100-year frequency flood at the site (see Appendix C) indicates that this is a depositional area and flow velocities are unlikely to erode the backfilled materials. No unacceptable human health or ecological risks will remain and the potential for degrading Raritan River Estuary quality by the remaining OU-3 river sediments is negligible. If upstream source areas (e.g. the SPD/ADC drainage) have not been controlled there will be a risk for recontamination of the remediated OU-3 river sediments. Regional monitoring performed to assess Raritan River Estuary quality will provide adequate control to ensure that recontamination does not occur. Regional monitoring performed to assess Raritan River Estuary quality will provide adequate control to ensure that recontamination does not occur. Periodic (5-year) review of conditions at the Horseshoe Road Site should provide adequate control to ensure that long-term performance of the remedy is effective. There will be no other need for long-term maintenance or monitoring specific to the OU-3 river sediments.
Reduction of Toxicity, Mobility, or Volume through Treatment	No treatment will be performed; therefore, there will be no reduction of toxicity, mobility, or volume through treatment.
Short-term Effectiveness	Dredging will result in short-term disruption of benthic invertebrate communities with indirect food-chain effects until recolonization and recovery of the benthic community occurs. Recovery is expected to be rapid. RAOs will be attained upon completion of the dredging and backfilling remedial actions, estimated to take approximately 1 to 2 months. Recovery of the site ecological communities to pre-remediation conditions is expected to take no more than 2 years.
Implementability	This alternative is implementable. Although the removal and backfilling activities in this intertidal area are challenging tasks, the equipment, materials, and skills needed to perform these actions are readily available. Similar actions have been implemented successfully at other sites with similar conditions.

Table 5-12. (cont.)

Evaluation Criteria	Evaluation	
Cost (See detailed cost estimate in Appendix E.)	Capital Cost Annual Operation and Maintenance Cost Total Periodic Cost Total Present Value	$5,490,000 $0 $820,000 $5,600,000

Table 5-13. Analysis of Alternative R5—Deep dredge and monitored natural recovery

Evaluation Criteria	Evaluation
Overall Protection of Human Health and the Environment	Although the only ecological risks identified for the OU-3 river sediments were limited effects on benthic organisms near the mouth of the SPD/ADC drainage, these will be eliminated by the removal of this material. Over time, monitored natural recovery will ensure that recontamination in excess of ambient conditions for the Raritan River does not occur. Human health risks will be reduced to acceptable levels either by removal under one of the OU-3 marsh remedial alternatives or by removal under this alternative.
Compliance with ARARs	No long-term exceedances of chemical-specific ARARs (e.g., water quality standards) are anticipated. Short-term localized exceedances of surface water quality standards are possible with this alternative during dredging and backfilling activities. Measures will be taken to meet potential chemical-specific ARARs to minimize surface water quality effects in accordance with the Clean Water Act and State of New Jersey Surface Water Quality Standards. Dredging activities will be conducted in a manner such that location-specific ARARs, such as the U.S. Rivers and Harbors Act and the Waterfront Development Act, will be met, and appropriate State of New Jersey permits for dredging activities on the waterfront will be obtained. For the potential offsite disposal of contaminated sediments, action-specific ARARs will have to be met. This will involve obtaining the appropriate permits (e.g., NPDES permits for the treatment and return discharge of Raritan River water generated during dredging) and complying with RCRA regulations for the transportation and disposal of solid waste. Alternative R5 will achieve compliance with ARARs.
Long-term Effectiveness and Permanence	Risks for adverse effects to human and ecological receptors within the dredged areas will be eliminated and essentially no residual contaminated sediments will remain. Regional monitoring performed to assess Raritan River Estuary quality will provide adequate control to ensure that recontamination does not occur. Periodic (5-year) review of conditions at the Horseshoe Road site should provide adequate control to ensure that long-term performance of the remedy is effective. There will be no other need for long-term maintenance or monitoring specific to the OU-3 river sediments.
Reduction of Toxicity, Mobility, or Volume through Treatment	No treatment will be performed; therefore, there will be no reduction of toxicity, mobility, or volume through treatment.
Short-term Effectiveness	Dredging will result in short-term disruption of benthic invertebrate communities with indirect food-chain effects until recolonization and recovery of the benthic community occurs. Recovery is expected to be rapid. All RAOs will be attained upon completion of the dredging remedial actions, estimated to take approximately 3 to 4 months. Recovery of the site ecological communities to pre-remediation conditions is expected to take no more than 2 years.
Implementability	The shallow conditions in this area present problems for mobilizing equipment and materials by barge, and will likely require intermittent activity dictated by tidal fluctuations. This will decrease the dredging production rate, but does not otherwise represent an insurmountable problem. Materials, equipment, and implementation expertise are readily available and the technology is reliable. Similar actions have been implemented successfully at other sites with similar conditions.
Cost (See detailed cost estimate in Appendix E.)	Capital Cost: $10,670,000 Annual Operation and Maintenance Cost: $0 Total Periodic Cost: $820,000 Total Present Value: $10,900,000

Table 5-14. Analysis of Alternative R6—Deep dredge and cover

Evaluation Criteria	Evaluation	
Overall Protection of Human Health and the Environment	Although the only ecological risks identified for the OU-3 river sediments were limited effects on benthic organisms near the mouth of the SPD/ADC drainage, these will be eliminated by the removal and replacement of this material. In addition, these activities will reduce the potential for exposure to contaminant concentrations in excess of ambient Raritan River conditions. Human health risks will be reduced to acceptable levels either by removal under one of the OU-3 marsh remedial alternatives or by removal under this alternative.	
Compliance with ARARs	No long-term exceedances of chemical-specific ARARs (e.g., water quality standards) are anticipated. Short-term localized exceedances of surface water quality standards are possible with this alternative during dredging and backfilling activities. Measures will be taken to meet potential chemical-specific ARARs to minimize surface water quality effects in accordance with the Clean Water Act and State of New Jersey Surface Water Quality Standards. Dredging and backfilling activities will be conducted in a manner such that location-specific ARARs, such as the U.S. Rivers and Harbors Act and the Waterfront Development Act, will be met, and appropriate State of New Jersey permits for dredging and backfilling activities on the waterfront will be obtained. For the potential offsite disposal of contaminated sediments, action-specific ARARs will have to be met. This will involve obtaining the appropriate permits (e.g., NPDES permits for the treatment and return discharge of Raritan River water generated during dredging) and complying with RCRA regulations for the transportation and disposal of solid waste. Alternative R6 will achieve compliance with ARARs.	
Long-term Effectiveness and Permanence	Risks for adverse effects to human and ecological receptors within the dredged areas will be eliminated and essentially no residual contaminated sediments will remain. Regional monitoring performed to assess Raritan River Estuary quality will provide adequate control to ensure that recontamination does not occur. Periodic (5-year) review of conditions at the Horseshoe Road Site should provide adequate control to ensure that long-term performance of the remedy is effective. There will be no other need for long-term maintenance or monitoring specific to the OU-3 river sediments.	
Reduction of Toxicity, Mobility, or Volume through Treatment	No treatment will be performed; therefore, there will be no reduction of toxicity, mobility, or volume through treatment.	
Short-term Effectiveness	Dredging and backfilling activities will result in short-term disruption of benthic invertebrate communities with indirect food-chain effects until recolonization and recovery of the benthic community occurs. Recovery is expected to be rapid. All RAOs will be attained upon completion of the dredging and backfilling remedial actions, estimated to take approximately 3 to 4 months. Recovery of the site ecological communities to pre-remediation conditions is expected to take no more than 2 years.	
Implementability	The shallow conditions in this area present problems for mobilizing equipment and materials by barge, and will likely require intermittent activity dictated by tidal fluctuations. This will decrease the dredging and backfilling rates, but does not otherwise represent an insurmountable problem. Materials, equipment, and implementation expertise are readily available and the technology is reliable. Similar actions have been implemented successfully at other sites with similar conditions.	
Cost (See detailed cost estimate in Appendix E.)	Capital Cost Annual Operation and Maintenance Cost Total Periodic Cost Total Present Value	$13,420,000 $0 $90,000 $13,500,000

Table 6-1. Summary of estimated costs for Horseshoe Road/ARC OU-3 marsh remedial alternatives

	Alternative						
	M1 No Action	M2 Channel Excavation and Thin Cover	M3 Surficial Hot Spot Removal and MNR	M4 Shallow Hot Spot Removal and Thin Cover	M5 Extended Shallow Removal and Thin Cover	M6 Extended Deep Removal and Thin Cover	M7 Complete Removal
Capital Cost	$0	$7,100,000	$7,670,000	$14,710,000	$16,600,000	$18,460,000	$20,530,000
Annual O & M Cost	$0	$1,700	$1,700	$1,700	$1,700	$1,700	$1,700
Total Periodic Cost	$300,000	$550,000	$550,000	$550,000	$450,000	$450,000	$250,000
Total Present Value	$100,000	$7,400,000	$8,000,000	$15,000,000	$16,900,000	$18,600,000	$20,700,000

Table 6-2. Summary of estimated costs for Horseshoe Road/ARC OU-3 river remedial alternatives

	Alternative					
	R1 No Action	R2 MNR	R3 Shallow Dredge and Thin Cap	R4 Extended Shallow Dredge	R5 Deep Dredge and MNR	R6 Deep Dredge and Cover
Capital Cost	$0	$240,000	$2,620,000	$5,490,000	$10,670,000	$13,420,000
Annual O & M Cost	$0	$0	$0	$0	$0	$0
Total Periodic Cost	$0	$820,000	$820,000	$820,000	$820,000	$90,000
Total Present Value	$0	$670,000	$2,800,000	$5,600,000	$10,900,000	$13,500,000

Table 7-1. Estimated areas, volumes, and total net present value costs for OU-3 marsh alternatives

Short Name	Alternative M1 No Action	Alternative M2 Channel Excavation and Thin Cover	Alternative M3 Surficial Hot Spot Removal and MNR	Alternative M4 Shallow Hot Spot Removal and Thin Cover	Alternative M5 Extended Shallow Removal and Thin Cover	Alternative M6 Extended Deep Removal and Thin Cover	Alternative M7 Complete Removal
SPD/ADC Channel Width 20 ft	---	excavate 3.0 ft	excavate 3.0 ft	excavate 3.0 ft	excavate 2.0 ft	excavate 3.0 ft	excavate 3.0 ft
Armored? (no/yes)	---	YES	NO	NO	YES	NO	NO
Area > 1050 mg/kg As 2.2 acres	---	excavate 0.0 ft	excavate 1.0 ft	excavate 2.0 ft	excavate 2.0 ft	excavate 2.5 ft	excavate 2.5 ft
		backfill/cover 0.5 ft	backfill/cover 1.0 ft	backfill/cover 2.0 ft	backfill/cover 2.0 ft	backfill/cover 2.5 ft	backfill/cover 2.5 ft
Area > 160 mg/kg As 2.4 acres	---	excavate 0.0 ft	MNR	excavate 0.0 ft	excavate 1.0 ft	excavate 1.5 ft	excavate 2.5 ft
		backfill/cover 0.5 ft		backfill/cover 0.5 ft	backfill/cover 1.5 ft	backfill/cover 1.5 ft	backfill/cover 2.5 ft
Area > 32 mg/kg As 1.4 acres	---	MNR	MNR	excavate 0.0 ft	excavate 0.0 ft	excavate 0.0 ft	excavate 1.0 ft
				backfill/cover 0.5 ft	backfill/cover 0.5 ft	backfill/cover 0.5 ft	backfill/cover 1.0 ft
In-place Excavation Volume	---	2,000 CY	4,883 CY	7,765 CY	10,971 CY	15,015 CY	21,145 CY
Excavated Volume (with over-excavation and fluff)	---	2,400 CY	7,989 CY	11,448 CY	17,618 CY	22,470 CY	31,182 CY
Disposal Volume							
Hazardous (with stabilization)	---	3,600 CY	11,983 CY	17,172 CY	15,972 CY	19,766 CY	19,766 CY
Non-hazardous	---	0 CY	0 CY	0 CY	6,970 CY	9,293 CY	18,005 CY
Debris (from clearing)	---	14,843 CY	7,099 CY	7,099 CY	14,843 CY	14,843 CY	19,360 CY
Total Backfill Area	---	0.3 acres	2.2 acres	2.2 acres	4.6 acres	4.6 acres	6 acres
Thin Cover Area		4.6 acres	0 acres	3.8 acres	1.4 acres	1.4 acres	0 acres
Backfill Volume	---	2,400 CY	7,989 CY	11,448 CY	19,941 CY	22,470 CY	24,856 CY
Total Present Value	$100,000	$7,400,000	$8,000,000	$15,000,000	$16,900,000	$18,600,000	$20,700,000

Table 7-2. Estimated areas, volumes, and total net present value costs for OU-3 river alternatives

Short Name		Alternative R1 No Action	Alternative R2 MNR	Alternative R3 Shallow Dredge and Thin Cap		Alternative R4 Extended Shallow Dredge		Alternative R5 Deep Dredge and MNR		Alternative R6 Deep Dredge and Cover	
Area > 194 mg/kg	0.8 acres	---	MNR	dredge	1.0 ft	dredge	1.0 ft	dredge	3.5 ft	dredge	3.5 ft
				cover / cap	1.0 ft	cover / cap	1.0 ft	cover / cap	0.0 ft	cover / cap	3.5 ft
Area > 100/2 mg/kg As/Hg	1.7 acres	---	MNR	dredge	0.0 ft	dredge	1.0 ft	dredge	3.5 ft	dredge	3.5 ft
				cover / cap	0.5 ft	cover / cap	1.0 ft	cover / cap	0.0 ft	cover / cap	3.5 ft
In-place Dredge Volume		---	0 CY	1,291 CY		4,033 CY		14,117 CY		14,117 CY	
Disposal Volume (with over-dredge and fluff)		---	0 CY	2,323 CY		7,260 CY		19,360 CY		19,360 CY	
Total Cap / Backfill Area		---	0 acres	2.5 acres		2.5 acres		2.5 acres		2.5 acres	
Backfill/Cap Volume		---	0 CY	1,936 CY		6,050 CY		0 CY		16,133 CY	
Thin-Cap Volume		---	0 CY	1,371 CY		0 CY		0 CY		0 CY	
Total Present Value		$0	$670,000	$2,800,000		$5,600,000		$10,900,000		$13,500,000	

Table 7-3. Cost matrix for combinations of OU-3 marsh and river remedial alternatives

			Total Net Present Value for Marsh Alternatives						
			M1	M2	M3	M4	M5	M6	M7
			$100,000	$7,400,000	$8,000,000	$15,000,000	$16,900,000	$18,600,000	$20,700,000
Total Net Present Value for River Alternatives	R1	$0	$100,000	$7,400,000	$8,000,000	$15,000,000	$16,900,000	$18,600,000	$20,700,000
	R2	$670,000	NA	$8,070,000	$8,670,000	$15,670,000	$17,570,000	$19,270,000	$21,370,000
	R3	$2,800,000	NA	$10,200,000	$10,800,000	$17,800,000	$19,700,000	$21,400,000	$23,500,000
	R4	$5,600,000	NA	$13,000,000	$13,600,000	$20,600,000	$22,500,000	$24,200,000	$26,300,000
	R5	$10,900,000	NA	$18,300,000	$18,900,000	$25,900,000	$27,800,000	$29,500,000	$31,600,000
	R6	$13,500,000	NA	$20,900,000	$21,500,000	$28,500,000	$30,400,000	$32,100,000	$34,200,000

Note: NA - not applicable; river Alternatives R2–R6 assume that an active remedial alternative will be implemented for the marsh.

Appendix A

Potential Applicable or Relevant and Appropriate Requirements

Table A-1. Potential applicable or relevant and appropriate requirements (ARARs)

Action/Application	Authority	Act	Criteria/Issues	Citation	Description
Chemical-Specific					
Soil	State of New Jersey		Direct Contact Soil Cleanup Criteria	N.J.A.C. 7:26D	Proposed remediation standards for soil and groundwater.
Surface Water	Federal	Quality Criteria for Water 1976, 1980, and 1986	Clean Water Act, Ambient Water Quality Criteria	40 CFR 131	Sets criteria for water quality based on protection of human health and protection of aquatic life.
Surface Water	State of New Jersey		Surface Water Quality Standards	N.J.A.C. 7:9B	Establishes classification of surface waters of the state, procedures for establishing water quality-based effluent limitations, and modification of water quality-based effluent limitations.
Surface Water	State of New Jersey	State Water Pollution Control Act	Surface Water Quality Standards	N.J.S.A. 58:10A	Establishes water quality standards for waters of the state and criteria to protect beneficial uses.
Air	State of New Jersey		State Air Quality Law and Noise Control	N.J.S.A. 26:2C. N.J.S.A. 13:1G	Provides general emission standards for fugitive emissions of air contaminants and requires the highest and best practicable treatment of control of such emissions. Prohibits any handling, transporting, or storage of materials, or use of a road, or any equipment to be operated, without taking reasonable precautions to prevent particulate matter from becoming airborne. Sets noise standards for equipment, facilities, operations, or activities employed in the production, storage, handling, sale purchase, exchange, or maintenance of a product, commodity, or service, including the storage or disposal of waste products.

Table A-1. (cont.)

Action/Application	Authority	Act	Criteria/Issues	Citation	Description
Action-Specific					
Upland Disposal	Federal	RCRA	Identification and Listing of Hazardous Waste	40 CFR 261	Identifies solid wastes that are subject to regulation as hazardous wastes.
Upland Disposal	Federal	RCRA	Standards Applicable to Generators of Hazardous Waste	40 CFR 262	Establishes requirements (e.g., EPA ID numbers and manifests) for generators of hazardous waste.
Upland Disposal	Federal	RCRA	Standards Applicable to Transporters of Hazardous Waste	40 CFR 263	Establishes standards that apply to persons transporting manifested hazardous waste within the United States.
Upland Disposal	Federal	RCRA	Standards Applicable to Owners and Operators of Treatment, Storage, and Disposal Facilities	40 CFR 264	Establishes the minimum national standards that define acceptable management of hazardous waste.
Upland Disposal	Federal	RCRA	Interim Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities	40 CFR 265	Establishes minimum national standards that define the periods of interim status and until certification of final closure or if the facility is subject to post-closure requirements, until post-closure responsibilities are fulfilled.
Upland Disposal	Federal	RCRA	Interim Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities	40 CFR 267	Establishes minimum standards that define acceptable management of hazardous wastes for new land disposal activities.
Upland Disposal	Federal	RCRA	Land Disposal Restrictions	40 CFR 268	Identifies hazardous wastes that are restricted from land disposal. All listed and characteristic hazardous waste, soil, or debris contaminated by a RCRA hazardous waste and removed from a CERCLA site may not be land disposed until treated as required by LDRs.
Upland Disposal	Federal	RCRA	Hazardous Waste Permit Program	40 CFR 270	Establishes provisions covering basic EPA permitting requirements.
Upland Disposal	State of New Jersey	Statutes and Rules	Hazardous Waste	N.J.A.C. 7:26C	Establishes rules for the operation of hazardous waste facilities in the state of New Jersey. Establishes cleanup authority and objectives.

Table A-1. (cont.)

Action/Application	Authority	Act	Criteria/Issues	Citation	Description
Upland Disposal	State of New Jersey	Hazardous Waste Regulations	Hazardous waste disposal regulations	N.J.A.C. 7:26G	Federally authorized state of New Jersey hazardous waste identification and management program that operates in lieu of the base federal program.
Upland Disposal	State of New Jersey	State Solid Waste Management Act	Statutory framework for solid waste disposal activities.	N.J.S.A. 13:1E-1	Establishes a statutory framework for solid waste collection, disposal, and utilization activities.
General Remediation	Federal	CERCLA	National Contingency Plan	40 CFR 300, Subpart E	Outlines procedures for remedial actions and for planning and implementing off-site removal actions.
General Remediation	Federal	OSHA	Worker Protection	29 CFR 1904	Requirements for recording and reporting occupational injuries and illnesses.
General Remediation	State of New Jersey	Soil Erosion and Sediment Control Act	Approval Requirements.	N.J.S.A. 4:24-1	Requirement for approval from the local soil conservation district (Freehold Soil Conservation District, Middlesex County) for projects that disturb more than 5,000 ft^2 of surface area of land.
General Remediation	State of New Jersey	Statutes and Rules	Technical Requirements for Site Remediation	N.J.A.C. 7:26E	Establishes minimum regulatory requirements for investigation and remediation of contaminated sites in New Jersey.
General Remediation	State of New Jersey	Technical Manual	The Management and Regulation of Dredging Activities and Dredged Material in New Jersey's Tidal Waters	New Jersey Department of Environmental Protection Technical Manual (1997)	NJDEP technical manual to make the permitting process for dredging activities and the management of dredged material clearer, less complicated, and more efficient. Includes best management practices.
Location-Specific					
Within 100-Year Floodplain	Federal	NEPA	Statement of Procedures on Floodplain Management and Wetlands Protection	40 CFR 6, Appendix A	Establishes EPA policy and guidance for carrying out Executive Order 11988—Floodplain Management. Action must avoid adverse effects, minimize potential harm, and restore and preserve natural and beneficial values of the floodplain.

Table A-1. (cont.)

Action/Application	Authority	Act	Criteria/Issues	Citation	Description
Within 100-Year Floodplain	State of New Jersey	Flood Hazard Control Act	Floodplain Use and Limitations	N.J.A.C. 7:13	State standards for activities within flood plains.
Wetlands	Federal	NEPA	Statement of Procedures on Floodplain Management and Wetlands Protection	40 CFR 6, Appendix A	Executive Order 11990—Protection of Wetlands—defines wetlands. Action must avoid to the extent possible the long and short term adverse impacts associated with the destruction or modification of wetlands.
Wetlands	State of New Jersey	Freshwater Protection Act	Permitting requirements	N.J.S.A. 13:9B-1; N.J.A.C. 7:7A	Require permits for regulated activity disturbing wetlands.
Wetlands	State of New Jersey	Wetlands Permit	Statement of Procedures for Work in wetlands	N.J.S.A. 13:9A-1	Restricts work type and mitigative measures necessary within a wetland.
Tidelands Conveyances	State of New Jersey	Riparian Grants, Leases and/or Licenses	Requirements for granting of conveyances		Tidelands grants, leases, and/or licenses are required for the use of state-owned riparian lands. These conveyances are granted by the Tidelands Resources Council.
Coastal Areas	Federal	Coastal Zone Management Act (1972) and Coastal Zone Act Reauthorization Amendments (1990)	Impacts to coastal resources	16 USC 1451 et seq; 16 USC 6217	Encourages states to develop coastal management plans to manage competing uses of and impacts to coastal resources, and to manage sources of nonpoint pollution in coastal waters.
Coastal Areas	State of New Jersey	Coastal Zone Management Program	Impacts to coastal resources	N.J.A.C. 7:7E	Standards for use and development of coastal resources in coastal waters to the limit of tidal influence (including the Raritan River).
Area Affecting Stream or River	Federal	Clean Water Act	Section 401(b)(1) Guidelines for Specification of Disposal Sites for Dredge or Fill Material; Section 404(c) Procedures; 404 Program Definitions; 404 State Program Regulations	40 CFR 230–233	Restricts discharge of dredged or fill material to wetlands or waters of the United States. Provides permitting program for situations with no other practical alternative.
Area Affecting Stream or River	Federal	Endangered Species Act	Protection of Threatened and Endangered Species	16 USC 1531 et seq.; 40 CFR 400	Standards for the protection of threatened and endangered species.

Table A-1. (cont.)

Action/Application	Authority	Act	Criteria/Issues	Citation	Description
Area Affecting Stream or River	Federal	Fish and Wildlife Conservation Act	Statement of Procedures for Non-game Fish and Wildlife Protection	16 USC 2901 et seq.	Establishes EPA policy and guidance for promoting the conservation of non-game fish and wildlife and their habitats. Action must protect fish or wildlife.
Area Affecting Stream or River	Federal	Rivers and Harbors Act	Regulates activity that may obstruct or alter a navigable waterway	33 USC 403 33 CFR 320-330	Regulations for filling, altering or modifying the course, location, condition, or capacity of a navigable waterway.
Area Affecting Stream or River	Federal	Migratory Bird Treaty Act	Protection of Migratory Birds	16 USC 703-702 50 CFR 10.12	Makes it unlawful to take, import, export, possess, buy, sell, purchase, or barter any migratory bird. "Take" is defined as pursuing, hunting, shooting, poisoning, wounding, killing, capturing, trapping, and collecting.
Area Affecting Stream or River	State of New Jersey	Coastal Area Facility Review Act Permit	Statement of Procedures for Work Within Coastal Areas	N.J.S.A. 13:19-1 et seq.	Establishes that coastal areas should be dedicated to land uses that protect public health and are consistent with laws governing the environment.
Area Affecting Stream or River	State of New Jersey	Waterfront Development Upland Waterfront Permit	Statement of Procedures for Work Within Waterfront	N.J.S.A. 12:5-3	Establishes the need for permitting when constructing or developing in coastal area between mean high tide. Waterfront development activities include, but are not limited to, the construction or addition of docks, wharves, piers, bridges, pipelines, dolphins, permanent buildings, and removal or deposition of subaqueous materials (dredging or filling).
Area Affecting Stream or River	State of New Jersey	Endangered and Non-Game Species Act	Protection of Threatened and Endangered Species	N.J.S.A. 23:2A-1	Standards for the protection of threatened and endangered species.
Area Affecting Stream or River	State of New Jersey	Flood Control Facilities Act	Statement of procedures for construction, operation, planning, or acquiring flood control facilities	N.J.S.A. 58:16A-50 et seq.; N.J.A.C. 7:8-3.15	Standards to construct, operate, or acquire a flood control device.

Table A-1. (cont.)

Action/Application	Authority	Act	Criteria/Issues	Citation	Description
General Remediation	Federal	National Historic Preservation Act	Procedures for preservation of historical and archaeological data	16 USC 469 et seq.; 40 CFR 6301(c)	Establishes procedures to provide for preservation of historical and archaeological data that might be destroyed through alteration of terrain as a result of a federal construction project or a federally licensed activity or program.

Note:

CERCLA	-	Comprehensive Environmental Response, Compensation and Liability Act of 1980
N.J.A.C.	-	New Jersey Administrative Code
N.J.S.A.	-	New Jersey Statutes Annotated
NEPA	-	National Environmental Policy Act
OSHA	-	Occupational Safety and Health Administration
RCRA	-	Resource Conservation and Recovery Act
USC	-	United States Code

Appendix B

Ecological Preliminary Remediation Goals

Exponent®

EXTERNAL MEMORANDUM

TO: John Osolin

FROM: Betsy Henry

DATE: July 27, 2007

PROJECT: BE02578.001

SUBJECT: Calculation of Ecological PRGs for the Horseshoe Rd/ARC OU-3 Site

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This memorandum describes the process we used to calculate site-specific preliminary remediation goals (PRGs) for marsh sediment based on information provided in the Horseshoe Rd/ARC OU-3 baseline ecological risk assessment (BERA) (Exponent 2006). This memorandum was revised based on comments provided by EPA on an April 17, 2007 draft memo. The BERA assessed risk to the short-tailed shrew, muskrat, and the marsh wren. As discussed in the screening level ecological risk assessment addendum (CDM 2002), small mammals, such as shrews and voles, are unlikely to reside in the *Phragmites* marsh, especially with more favorable habitat located adjacent to the marsh. In general, *Phragmites* marshes are considered to provide low-quality nesting and foraging habitat for mammals. Given the low likelihood that the shrew or other small mammals would reside exclusively in the marsh, PRGs for small mammals (e.g., the short-tailed shrew) were not developed. PRGs were developed for protection of the marsh wren and muskrat.

Background

In the BERA, food-web exposure models were developed to estimate site-specific daily doses of contaminants for the marsh wren and the muskrat. Hazard quotients were then determined as the ratio of the exposure estimate (i.e., the daily dose of contaminant ingested via all exposure routes) to toxicity reference values (TRVs) derived from toxicological studies reported in the scientific literature. These included both no-observed-adverse-effects level and lowest-observed-adverse-effects level (LOAEL) hazard quotients. The hazard quotients based on the LOAELs are considered most relevant for judging the potential for effects because they represent the lowest doses at which adverse effects have been observed in studies. The approaches for using food-web exposure models to estimate PRGs for marsh wren and muskrat are discussed in the following sections.

Calculation of Marsh Wren PRGs

For the marsh wren, the PRGs for each contaminant were determined by first ranking the stations and BERA-calculated LOAEL hazard quotients based on contaminant concentration, and then identifying the contaminant concentration that corresponded to a hazard quotient of one (see Table 1). In the case of mercury, the PRG was identified as the upper end of the range of mercury concentrations within which the hazard quotient increased from less than one to greater than one (i.e., in effect, a LOAEL). For polychlorinated biphenyls (PCBs), all LOAEL hazard quotients were less than one, so the PRG was defined as greater than the highest observed contaminant concentration.

Table 1. Station-specific contaminant concentrations and hazard quotients used to estimate PRGs for the marsh wren

Arsenic			Mercury			Polychlorinated Biphenyls		
Station	Concen-tration (mg/kg)	Hazard Quotient	Station	Concen-tration (mg/kg)	Hazard Quotient	Station	Concen-tration (mg/kg)	Hazard Quotient
17	17,800	12	17	68.0	31	22	**20.0**	0.89
12	**1,470**	1	12	20.5	9.4	17	7.20	0.21
16	1,050	0.86	16	15.5	63	12	2.60	0.077
13	67.5	0.067	22	10.5	19	11A	2.20	0.18
REF3	49.9	0.041	19	8.86	8.9	19	1.40	0.11
14	43.2	0.05	11A	3.60	2.6	16	1.20	0.16
REF1	38.9	0.032	14	2.82	1.9	14	0.87	0.051
22	34.3	0.039	REF3	1.4	2.2	REF3	0.77	0.027
11A	31.6	0.037	13	0.88	3.5	13	0.57	0.057
19	16.6	0.026	REF1	**0.76**	2.4	REF1	0.28	0.015
18A	12.0	0.023	18A	**0.42**	0.89	18A	0.10	0.041
13A	9.34	0.031	REF2	0.18	0.56	REF2	0.098	0.0078
REF2	6.68	0.019	13A	0.07	0.72	13A	0.04	0.038

Note: Values in bold are PRGs.

Using this approach, the marsh wren PRGs are 1,470 mg/kg, 0.76 mg/kg, and > 20 mg/kg for arsenic, mercury, and PCBs, respectively. The mercury PRG appears to be the least certain, with a potential PRG less than background concentrations measured at the reference location.

The low mercury PRG results from assumptions made regarding mercury speciation (i.e., total mercury versus methylmercury) in TRVs and prey items. Methylmercury is the most toxic form of mercury; however, sediment analyses are often conducted just for total mercury, which includes inorganic mercury species as well as methylmercury. Food web exposure models in the BERA assumed that all mercury present in sediment, insects, and blackworms was methylmercury, and compared the total estimated exposure concentration to a methylmercury

TRV. However, as discussed in the BERA, methylmercury concentrations in sediment are generally low and make up <0.1 to 16 percent of total mercury (Gilmour and Henry 1991). More recent work has found that methylmercury is generally between only one and ten percent of total mercury in soil and sediment of aquatic ecosystems, and that little additional methylmercury is produced as total mercury exceeds 1 mg/kg (Krabbenhoft et al. 1999). Furthermore, the percent methylmercury in insects and blackworms is generally less than 100 percent. For example, a study of percent methylmercury in insects along the South River, Virginia, yielded a mean value of 66 percent methylmercury for *Diptera*, *Ephemeroptera*, and *Trichoptera* (unpublished data). Also, a comprehensive survey of methylmercury and total mercury concentrations in benthic macroinvertebrates in Onondaga Lake reported a mean value of 26 percent methylmercury in these organisms (Becker and Bigham 1995). Thus, the assumption that 100 percent of the mercury in sediment, insects, and blackworms is methylmercury overpredicts toxicity to wrens.

For purposes of calculating a mercury PRG, exposure models were re-run to adjust the total mercury concentrations in sediment and food by the proportion that is methylmercury. For sediment, 1 percent of the total mercury is assumed to be methylmercury. For insects, 66 percent of the mercury is assumed to be methylmercury and, for blackworms, the proportion is assumed to be 26 percent. Results are presented in Table 2.

Table 2. Station-specific contaminant concentrations and hazard quotients used to estimate mercury PRG for the marsh wren based on methylmercury

	Mercury		Methylmercury
Station	Concen-tration (mg/kg)	Hazard Quotient	Hazard quotient when: Sediment = 1% MeHg Insect = 66% MeHg Worm = 26% MeHg
17	68.0	31	1.1
12	20.5	9.4	0.53
16	15.5	63	14.9
22	10.5	19	4.0
19	8.86	8.9	**1.6**
11A	3.60	2.6	**0.53**
14	2.82	1.9	0.45
REF3	1.4	2.2	0.53
13	0.88	3.5	1.1
REF1	0.76	2.4	0.65
18A	0.42	0.89	0.43
REF2	0.18	0.56	0.22
13A	0.07	0.72	0.42

As indicated by hazard quotients in the table, when media are adjusted for the proportion of methylmercury, the mercury PRG (8.86 mg/kg) is higher than estimated based on total mercury concentrations. At mercury concentrations equal to or greater than 8.86 mg/kg, hazard quotients were greater than one, with one exception (Station 12 with a hazard quotient of 0.53 and a mercury concentration of 20.5 mg/kg). At mercury concentrations equal to or less than 3.6 mg/kg, hazard quotients were less than one, with one exception (Station 13, with a hazard quotient of 1.1 and a mercury concentration of 0.88 mg/kg). This exception probably reflects the lack of tight correlation between methylmercury concentrations in sediment and worms. Exposure (and thus, hazard quotient) is most greatly influenced by the latter, with approximately 85–90 percent of total exposure to mercury for wrens resulting from the diet.

Calculation of Muskrat PRGs

The approach for calculating PRGs for marsh wrens was not applied to muskrat, because the BERA calculated site-wide hazard quotients for muskrat assuming that an individual could potentially forage across the entire marsh. Additionally, vegetation samples were analyzed only at a subset of marsh stations, so it is not possible to rank all stations according to hazard quotient, as was done for marsh wren, without encountering large gaps between sequential sediment concentrations, which would result in considerable uncertainty when establishing a PRG.

The alternate approach used for muskrat establishes a PRG by setting the LOAEL hazard quotient to one, and then running the model backward to find the corresponding sediment concentration. To circumvent the problem of limited vegetation data, plant tissue concentrations are estimated from sediment concentrations using bioaccumulation factors (BAFs) from the scientific literature. The approach is explained in more detail in the following paragraph.

Plant uptake factors for arsenic and mercury were obtained from Bechtel Jacobs (1998). For arsenic a BAF of 0.029 was used based on the regression equation for arsenic presented in Table 7 of Bechtel Jacobs (1998). For mercury, a BAF of 0.025 was used based on the regression equation for mercury presented in Table 8 of Bechtel Jacobs (1998). The regression equation for mercury includes pH as a variable. For these calculations, a pH of 6.2 was used, which represents the average value for all site marsh and upland stations (see Table C-6 of the BERA). For PCBs, a BAF of 0.01 was used as recommended in U.S. EPA (1999). Regression equations predict plant concentrations on a dry weight basis. However, the food web exposure models require plant concentrations on a wet weight basis. An average moisture content of 57 percent was used based on plant tissue data presented in Table C-10 of the BERA. To calculate PRGs, food-web model spreadsheets were run in Microsoft Excel®. The LOAEL hazard quotient was set at 1.0, and the Solver function of the program was used to calculate a corresponding sediment concentration. Plant tissue concentrations were linked to sediment concentrations using the BAF values stated above, so the program adjusted both sediment and plant concentrations to achieve a hazard quotient of 1.0.

The calculated PRGs were 183 mg/kg for arsenic, 24 mg/kg for mercury, and 62 mg/kg for PCBs. The mercury PRG was not adjusted for percent methylmercury in sediment or plants. Adding this variable would result in a higher PRG. The mercury and PCB PRGs are higher than the corresponding value for wrens, while the arsenic value is approximately ten-fold less than the wren PRG.

Summary

In summary, site-specific sediment PRGs were calculated for the marsh wren and muskrat. Respectively, these PRGs were 1,470 and 183 mg/kg arsenic, 8.86 and 24 mg/kg mercury, and >20 and 62 mg/kg PCBs.

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Appendix C

Flood Scour Analysis

Flood Scour Analysis

Introduction

In order to evaluate remedial alternatives for the Horseshoe Road/Atlantic Resources Corporation Operable Unit 3 (OU-3) sites, collectively the Sites, it was necessary to estimate scour velocities and erosion potential in the OU-3 river and marsh areas. The selected approach was to analyze available data on sediment characteristics at the site and to estimate permissible scour velocities based on this characterization. These estimated velocities were then compared to average flow velocities based on the Federal Emergency Management Agency (FEMA) flood mapping of the study area, to determine whether locations at the site can be characterized as being either erosional or depositional. Additionally, flow velocities were calculated for the SPD/ADC drainage channel using the U.S. Army Corps of Engineers' Hydraulic Engineering Center River Analysis System (HEC-RAS) computer model and then compared with the permissible velocities of the sediment and soil samples in the vicinity of the channel.

The analysis presented herein is a screening level analysis. It is based on available information on sediment samples collected by CDM in 1997 and Exponent in 2004; information cited in the Flood Insurance Study (FIS) for the Borough of Sayreville dated January 16, 1987 (FEMA 1987); the results of the hydraulic analysis carried out by FEMA for Middlesex County from Fall 1976 to Spring 1977 (HUD 1977); and the results of the HEC-RAS analysis.

The following sections present our analyses of the particle size distributions (PSDs) and estimation of permissible velocities based on the median particle size (D_{50}), comparison of the estimated permissible velocities with average flow velocities, and conclusions of the analyses.

Particle Size Distributions and Permissible Velocities

Two sources of data were used to characterize the sediments in the vicinity of the OU-3 river and marsh areas. The first set of data was extracted from the *Final Screening Level Ecological Risk Assessment Horseshoe Road Complex Site Remedial Investigation/Feasibility Study Sayreville, New Jersey* (CDM 2000). Samples were collected by CDM in 1997. The second set of data was collected by Exponent in 2004. Data were presented in *Baseline Ecological Risk Assessment Operable Unit 3, Horseshoe Road and Atlantic Resources Corporation Sites* (Exponent 2006).

CDM 1997 Data

The first set of data, collected by CDM in October, November, and December 1997, consists of nine surface samples (identified with the prefix SS) and 39 sediment samples (identified with the prefix SD). One sediment sample, SD04, was discarded because of an unreliable data point. All samples were hand-collected using a trowel within 6 in. of the ground surface. The sample locations are shown in Figures C-1 and C-2. Tables C-1 and C-2 show the grain size distribution data adapted from the raw data, which are presented in Attachment C-1.

The samples were analyzed for PSDs, and corresponding median particle size (D_{50}). The D_{50} values were bilinearly interpolated from the data. PSD curves for the samples are shown in Figures C-3 and C-4. The PSD curves indicate that the samples are non-uniform, with sediments ranging in size from coarse sand to clay. The D_{50} data for the samples vary from 0.050 to 0.512 mm for the surface samples, and 0.002 to 0.504 mm for the sediment samples. Tables C-3 and C-4 summarize the D_{50} data for each of the samples along with the soil classification based on the D_{50} values. Plots of the D_{50} values (Figures C-5 and C-6) show the variation of D_{50} for the surface and sediment samples.

The variation of the median particle size (D_{50}) for the sediment samples along the length of the river is shown in Figure C-7. Generally, there is a decrease in D_{50} from the upstream to the downstream ends of the channel, though the trend is not pronounced. This indicates that fine-grained sediments are likely to be deposited in downstream areas as a result of flow velocities that are sufficiently small to allow deposition. Coarser-grained sediments that have higher settling velocities would tend to deposit at upstream locations. The source of fine-grained sediments could be from upstream sources or from backwater effects in the Raritan River during flooding of the river and marsh areas. Figure C-8 shows the longitudinal variation in D_{50} values from the upstream to the downstream ends of the OU-3 channel.

Permissible velocities for erosion for each D_{50} were computed using Figure 7-3 of Chow (1959), shown here as Figure C-9 for completeness. Velocities are shown in Tables C-3 and C-4, for the surface and sediment samples, respectively. Permissible velocities range from approximately 0.7 to 1.3 feet per second (fps) for the surface samples, and from approximately 0.5 to 1.3 fps for the sediment samples.

Exponent 2004 Data

The second set of data was 30 soil samples from the OU-3 marsh area and its vicinity, collected by Exponent during October and November 2004. Sample locations are shown in Figure C-10. The raw data are presented in Attachment C-2. Exponent's sediment samples were collected within the top 6 in. of the ground surface.

The Exponent data classifies the particle size in terms of the sedimentological Φ scale, according to $\Phi = -\log_2(\mathrm{D}) = \dfrac{-\ln(\mathrm{D})}{\ln(2)}$, in which D is the particle size. Thus, Φ = 0 corresponds to D = 1 mm. The Φ values were converted to the particle size in mm as shown in Table C-5. The D_{50} values were bilinearly interpolated from the data. PSD curves for the samples are shown in Figure C-11. The PSD curves indicate that the samples are non-uniform, with sediments ranging in size from gravel to silt. Particle size information for size less than 0.005 mm was not available. The D_{50} values for the samples vary from 0.007 to 0.57 mm. Table C-6 summarizes the D_{50} data for each of the samples along with the soil classification based on the D_{50} values.

Figure C-12 shows the D_{50} values at several sampling locations in the OU-3 river and marsh areas. No observable trend is apparent for the distribution of the D_{50} values along the length of the river. The sampling is focused on the marsh area directly adjacent to the Raritan River, preventing a thorough analysis of the variability in D_{50} along the full extent of the OU-3 channel.

Permissible velocities for erosion for each D_{50} are shown in Table C-6 using Figure 7-3 of Chow (1959). The values range from 0.5 to 1.4 fps.

Discussion on Permissible Velocities

Based on our analyses of the CDM and Exponent data sets, the permissible velocities for the estimated D_{50} values are within a similar range of values between 0.5 to 1.4 fps. Permissible velocities refer to the maximum flow velocities that can exist without causing sediment erosion. The maximum permissible velocities are not steadfast, as old channels typically can sustain higher velocities before erosion occurs (Chow 1959). If the near-bed flow velocity exceeds the permissible velocity, then the sediments are liable to erode. It is important to note that these permissible velocities are determined using the assumption that the soils are noncohesive. Noncohesive sediments are primarily sand and gravel-sized material. If localized areas of purely non-uniform noncohesive sediments existed, these sediments would be entrained into the water column, provided the bed shear velocities were greater than the critical shear velocity of the bed grains and the settling velocity of the particles. The maximum amount entrained into the water column is based on the carrying capacity of the flow. However, because of the non-uniform nature of the sediments, when the finer fraction of the noncohesive sediments was entrained, the coarser fractions would be exposed to the flow, which would require a higher bed shear velocity to entrain them. In addition, non-uniform noncohesive sediment exhibits a hiding effect, where some of the finer sediments will be hidden from exposure to the flow by the coarser-grained sediments. Both these mechanisms would result in armoring of the sediment bed and erosion will cease.

Based on the examination of the PSD data, it is evident that the bed sediments are not only non-uniform but also consist of fractions of fine-grained sediments (i.e., clay and silt) that would cause the sediment mixture to exhibit the properties of cohesive sediments. Van Rijn (1993) notes that if the clay fraction in a sediment mixture is greater than 0.10, then the sediments can be characterized as cohesive sediments. The resuspension behavior of cohesive sediments is different from that of noncohesive sediments. First, the resuspension potential is limited to a maximum amount for any given bed shear stress. Second, cohesive sediments consolidate with time such that the strength of the bed sediments increases with depth below the sediment-water interface. Thus, a larger bed shear stress would be required to resuspend these sediments.

Vegetated channels and floodplains would retard the flow, increasing the depth of flow and decreasing velocities. This is a result of an increase in the flow resistance (Manning's roughness coefficient). This not only enhances the deposition of sediments but also decreases the potential for erosion of bed sediments because the bed shear stresses induced at the sediment-water interface are lower. Estimation of D_{50} and permissible velocities in our analyses did not include the effect of vegetation in retarding flows in the OU-3 river and marsh areas.

Flow Velocities Derived from FEMA Data

The Floor Insurance Rate Map (FIRM) for the vicinity of the Horseshoe Road site was obtained from FEMA. Figures C-13 and C-14 illustrate the approximate water surface elevations that would result from the 100-year flood in the vicinity of the site. The FIRM is presented in Figure C-13 and Figure C-14 shows the approximate delineation of the 100-year floodplain on a topographic map of the project site. The FIRM indicates that the project site is in the flood zone designated as Zone A5, which corresponds to an area where the water surface elevations for the 100-year flood have been determined.

HEC-2 model results and the FIS for the Borough of Sayreville were obtained from FEMA. The HEC-2 model provided information on the flows, water depths, water surface elevations, top widths, and cross-section data for a number of locations along the Raritan River. The sections are mapped as shown in Figure C-15. (All information was available only as hard copies.) Given the absence of digital data, it was not possible to re-run the HEC-2 model for additional sections in the vicinity of OU-3 river and marsh areas. Hence the hydraulics in the vicinity of the site were calculated from information obtained between Sections C and D shown in Figure C-15. The velocities corresponding to the 100-year flow for several cross-sections are tabulated in Table C-7. The floodway velocities at Sections C and D are about 1.6 fps. The HEC-2 information did not provide any velocities in the floodplain or in the vicinity of overbank areas, hence comparison of velocities could not be made with permissible velocities in the OU-3 river and marsh areas. The 10-, 50-, 100-, and 500-year flows for two locations along the Raritan River are tabulated in Table C-8.

The 100-year and 500-year floodplain elevations shown on the 1987 FIRM for Community-Panel Number 340276 0002 C are of a large scale and difficult to overlay on the project site to provide a detailed resolution image of the floodplain relative to the project site. The specifics regarding the computations used to establish the extents of the 100-year and 500-year floodplains along the Raritan River obtained from FEMA were only available in the form of hardcopies of the HEC-2 computer model input and output, in which most of the values were illegible. Given the lack of digital data, it was not possible to delineate the floodplain in a more accurate fashion. Instead, the 100-year and 500-year water surface elevations shown in the 1987 FIS for the Borough of Sayreville, New Jersey, were used to evaluate the location of the floodplain relative to the project site. This document shows that the 100-year and 500-year floodplains are at elevations of 10.0 ft and 10.2 ft, respectively at Cross-Section D (i.e., closest to the project site). The elevations are relative to NGVD 29. These data were then used to map the approximate 100-year floodplain on a topographic map of the site as shown in Figure C-14. The procedure adopted was to delineate the floodplain based on contour elevations corresponding to the 100-year water surface elevations. Because of lack of detail in the known topography, depicting the 500-year water surface elevation would not differ dramatically from that shown for the 100-year water surface.

Flow Velocities near the Overbank Areas of OU-3 River and Marsh Areas

The FIS shows the calculated water surface profile for the 10-, 50-, 100-, and 500-year floods. The water surface elevation for the 100-year flood at cross section D (the cross-section nearest to the OU-3 river and marsh area) is 106.33 ft, which corresponds to an elevation of approximately 10 ft relative to the 1929 national geodetic vertical datum.

HEC-2 information was used to depict a schematic of cross section D (looking upstream) as shown in Figure C-16. As mentioned earlier, Section D is the HEC-2 cross section that is closest to the OU-3 river and marsh areas. Because digital HEC-2 data were not available to rerun the HEC-2 model for estimation of velocities in the overbank areas or to interpolate between cross sections, Section D was used to estimate the velocities in the vicinity of the left bank to get an idea of the flow velocities there. By discretizing the cross section into subsections, the velocity (*v*) in each subsection was computed using Manning's formula in English units:

$$v = \frac{1.49}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \tag{1}$$

where:

n	=	Manning's roughness coefficient
R	=	hydraulic radius (ft) = A/P
S	=	water surface slope
A	=	area of flow (ft^2)
P	=	wetted perimeter (ft).

The HEC-2 model used n = 0.035 and the slope was estimated from the model output as S = 0.0006.

Velocities at subsections in the vicinity of the left bank (looking upstream) were estimated to range from 0.10 to 0.4 fps, spanning a distance of approximately 200 ft from the left bank of Section D. It is important to note that the velocities estimated at the subsections represent the mean velocities and not the near-bed velocities. It is the near-bed velocity that induces a shear stress at the sediment water interface, resulting in erosion if the critical shear stress for erosion of the bed sediments is exceeded. For the purposes of this study, mean velocities were compared to the permissible velocities. Mean velocities were all less than the permissible velocities computed for the bed sediment samples, which ranged from 0.5 to 1.4 fps. The presence of vegetation in the marsh area would decrease the flow velocities. In addition, the mechanism of sediment armoring would tend to reduce erosion of sediments.

Based on the above information, sediment in the OU-3 river and marsh areas at the sampling locations does not appear to be susceptible to erosion as a result of 100-year flows in the Raritan River. It should be noted here that the approach used is a screening-level analysis, given the limited information from the FEMA study and the absence of information on flows from the river.

Flow Velocities in SPD/ADC Drainage Calculated Using HEC-RAS

A hydrologic and hydraulic analysis was conducted to estimate the potential for scour of sediments in the SPD/ADC drainage channel and adjacent floodplain resulting from storm runoff from upland areas. The upland area contributing to the SPD/ADC drainage channel was assumed to be the drainage basin encompassing the SPD/ADC sites, and is labeled as the OU2 drainage basin as shown in Figure C-17. The drainage is constrained on the west and north by roadways, on the east by the railroad embankment, and on the south by the topography. The drainage area was estimated to be approximately 8.8 acres.

Hydrologic Analysis

The peak flow entering the SPD/ADC drainage was computed using the Rational Method formula for small basins

$$Q_p = CIA \tag{2}$$

where:

- Q_p = peak discharge (cfs)
- C = dimensionless runoff coefficient whose value depends on the hydrologic characteristics of the drainage area
- I = rainfall intensity (in./hour) for a duration equal to the time of concentration (t_c) of the drainage basin
- A = area of the drainage basin (acres).

The time of concentration (t_c) was estimated from the following equation (SCS 1972) taken from Singh (1992):

$$t_c = \frac{L^{1.15}}{7700H^{0.38}} \tag{3}$$

where:

- t_c = time of concentration (hour)
- L = length of travel from the most remote point on the drainage basin along the drainage channel to the basin outlet (ft)
- H = difference in elevation between the most remote point on the drainage basin to the basin outlet (ft).

Using L = 950 ft, H = 24.4 ft, t_c = 0.102 hour = 6.1 minutes.

The 100-year rainfall intensity (I) for t_c = 6.1 minutes was estimated from NOAA Atlas 14 (Attachment C-3) to be 7.6 in./hour.

The runoff coefficient (C) for the drainage basin was assumed to be 0.25 for rural woodlands, with an average slope of 5–10% (Singh 1988). Our assumption is based on the hydrologic characteristic of the SPD/ADC drainage basin for post-remediation conditions (i.e., a marsh landscape/environment). For C = 0.25, I = 7.6 in./hour, and A = 8.8 acres, the peak discharge at the basin outlet was estimated from Equation (2) to be 17 cfs.

Hydraulic Analysis

A steady-state hydraulic analysis was conducted using HEC-RAS (Version 3.1.3 released in May 2005) to better understand the potential for erosion in the SPD/ADC drainage channel as a result of runoff from the upstream watershed. The analysis considered runoff from the SPD/ADC drainage area, and it was assumed that flow in the Raritan River would cause some water in the main river to encroach on the lower extent of the OU-3 marsh area, and thus cause a backwater effect (i.e., the width of the main Raritan River would widen as a result of the flood event and water from the channel would cause a rise in the water surface in the vicinity of the outlet of the SPD/ADC channel.) A 100-year event in the area would likely influence an area greater than just the SPD/ADC drainage area and channel, so it is reasonable to assume that there would be some backwater influence from the Raritan River.

Figure C-17 shows the locations of the HEC-RAS cross-sections. The cross-sectional profiles were determined using a topographic map of the area, which includes 1-ft contour intervals for elevations less than 10 ft NGVD 29 and 5-ft contour intervals for elevations greater than 10 ft NGVD 29. The lateral extent of the cross-sections encompasses the SPD/ADC drainage channel. The HEC-RAS model was simulated using the peak flow of 17 cfs that was computed above. Channel roughness was defined with Manning's n values of 0.04 and 0.07, for the channel and overbanks, respectively. Higher roughness values were defined for the overbanks to account for the added friction that would be caused by vegetation and other flow obstructions along the banks. The Manning's n values were adopted from representative values specified in the FIS (FEMA 1987).The downstream water surface elevation at Section 1 was specified to be the tidal elevation of 5.7 ft (FEMA 1987) to account for backwater effects on the OU-3 marsh area.

Erosion Potential of Onsite Sediments

The average velocities computed from the HEC-RAS model were compared with the permissible velocities for scour for selected onsite sediment and soil samples that were taken in the vicinity of the SDP/ADC drainage channel, which are shown in Table C-9.

The flow velocity distribution at each of the cross-sections is provided in Table C-10. The calculated velocities in the channel range from 0.04 fps to 2.58 fps. The left overbank velocities vary from 0.02 fps to 0.65 fps, and the right overbank velocities vary from 0.02 fps to 0.58 fps.

Generally, the channel velocities are greater than the permissible velocities of the sediment samples in the channel upstream of Section 3. Downstream of Section 3 and in the overbanks, the average velocities are lower than the permissible velocities of sediment samples. The results of the hydraulic analysis show that the sediments located in the upstream reaches of the SPD/ADC channel may be subject to erosion. The effect of sediment armoring and/or consolidation was not taken into account.

It is important to note that ultimately, the SPD/ADC drainage channel is planned to become an engineered channel. As such, the channel bottom can be armored to protect underlying sediments from potential erosion.

Conclusions

1. PSD curves were developed using CDM and Exponent datasets. The data sets were then used to estimate the median particle size (D_{50}) for each sample. The D_{50} varied from 0.050 to 0.512 mm for the CDM surface samples, 0.002 to 0.504 mm for the CDM sediment samples, and 0.007 to 0.57 mm for the Exponent samples. For the CDM data set, the D_{50} decreased downstream with longitudinal distance along the river, but the trend was not pronounced. For the Exponent data set, there were only a few samples collected in the vicinity of the river; hence, there was no observable trend in D_{50} in the longitudinal direction.

2. Permissible velocities for erosion of the bed sediments were estimated from the D_{50} values. Permissible velocities are based on the assumption that the sediments are noncohesive. The permissible velocities for the CDM and Exponent samples are similar, ranging from 0.5 to 1.4 fps.

3. The FEMA HEC-2 model did not provide predictions of the velocities in the vicinity of the OU-3 river and marsh areas. A hard copy of the HEC-2 model was used to generate a plot of the cross-section closest to the project site. Velocities at various locations along the cross section were estimated for the 100-year flow. These velocities were compared with the permissible velocities for erosion determined above. Based on our analysis, it appears that the flow velocities in the bank area are approximately 0.10 to 0.4 fps, which is less than the permissible velocities for sediments in the OU-3 river and marsh areas (i.e., 0.5 to 1.4 fps). Therefore, it can be concluded that bed sediments at the sampling locations are unlikely to erode for the given flow. The effect of any vegetation in the OU-3 river and marsh areas was not considered in this evaluation. The presence of vegetation in the marsh areas would retard flow velocities as a result of increased resistance to flow (i.e., higher Manning's roughness coefficient, *n*) making the bed sediments less susceptible to erosion. Also, the presence of different size classes at any location would allow for armoring effects. These two considerations would likely decrease the potential for erosion of the bed sediments. To quantify the extent of erosion over the entire OU-3 river and marsh areas, it would be necessary to actually simulate the hydraulics and sediment transport at the site for existing boundary conditions of topography, flow, and tidal boundary conditions.

4. A steady-state hydraulic analysis showed that the channel velocities in the SPD/ADC for a 100-year storm event are generally greater than the permissible velocities of sediment samples in the approximately 670-ft length of channel downstream of the culvert location (i.e., from the culvert outlet to Section 3 of the HEC-RAS model). However, the sediment samples in the overbanks and channel near the confluence of the SPD/ADC drainage channel and the Raritan River would not be subject to erosion. Because the SPD/ADC drainage channel will be converted to an engineered channel, bed armoring can be provided to prevent erosion of the underlying soils and sediments.

5. It is evident that the sediments in the OU-3 river and marsh areas consist of cohesive sediments. The processes influencing cohesive sediment transport are different from that for noncohesive sediments. It is necessary to adequately characterize the erosive behavior of these sediments to assess their transport during various flow conditions. Because cohesive sediments consolidate with time, bed sediments become less susceptible to erosion with depth of sediment. In addition, for a certain shear stress, only a finite amount of sediment can erode.

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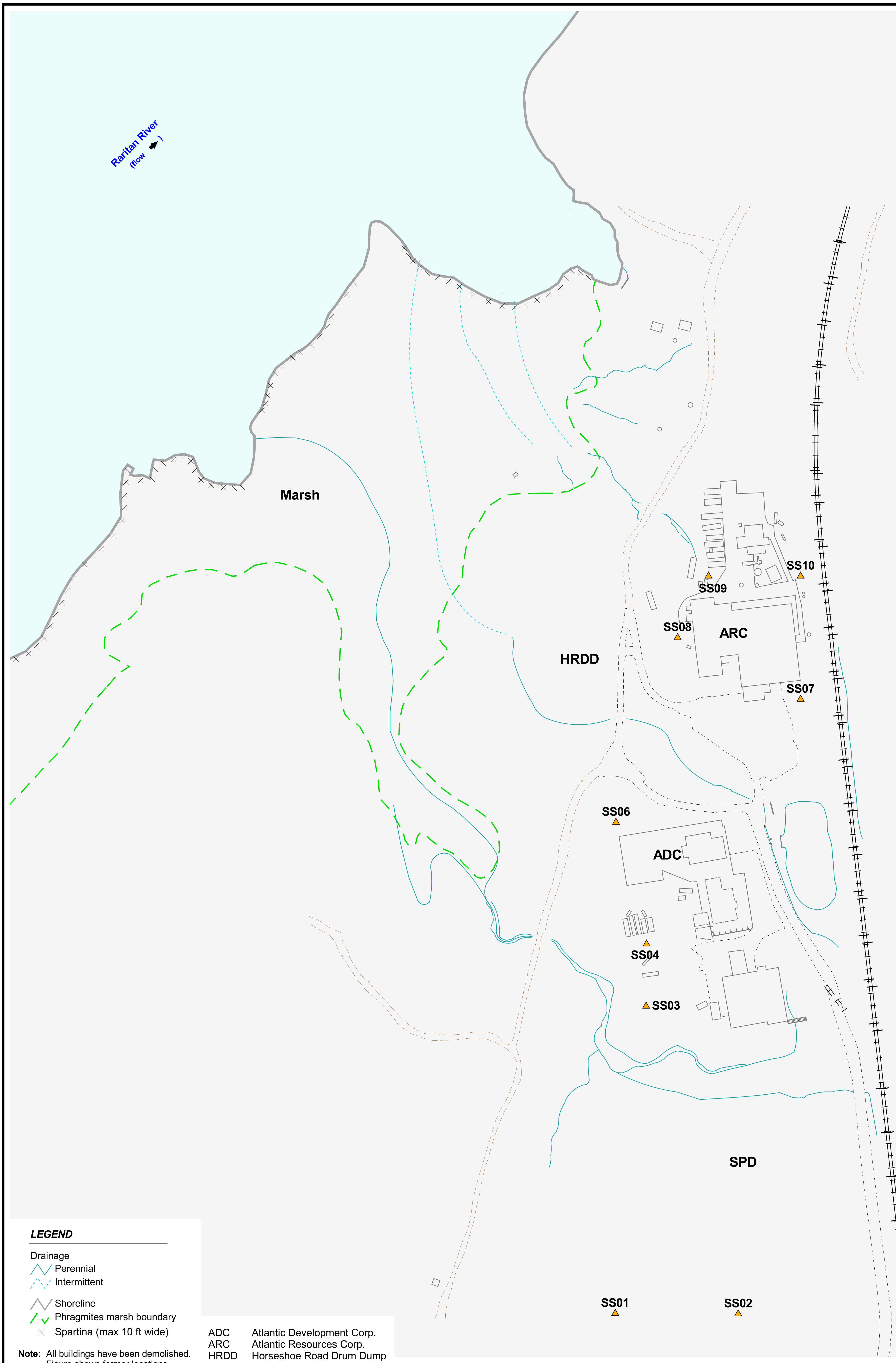
Figures



Exponent®

0 150 300 Feet
0 50 100 Meters

Figure C-1. Location map of CDM 1997 surface soil samples

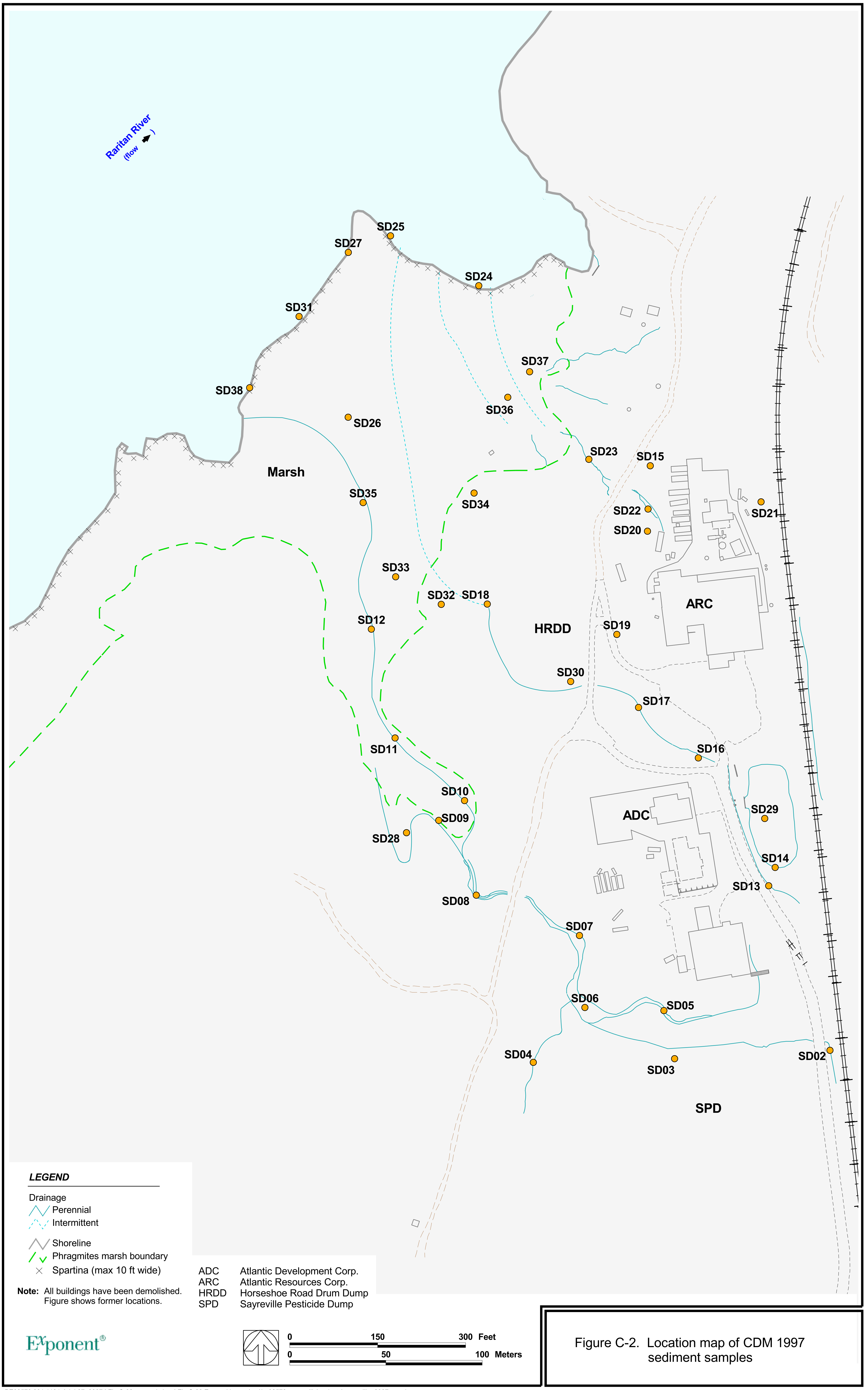


Figure C-2. Location map of CDM 1997 sediment samples

BE02578.001 1104 | Jul 27, 2007 | Fig C-02 env sed view | Fig C-02 Env sed layout | m:\be02578_sayreville\projects\sayreville_2007_appd_c.apr

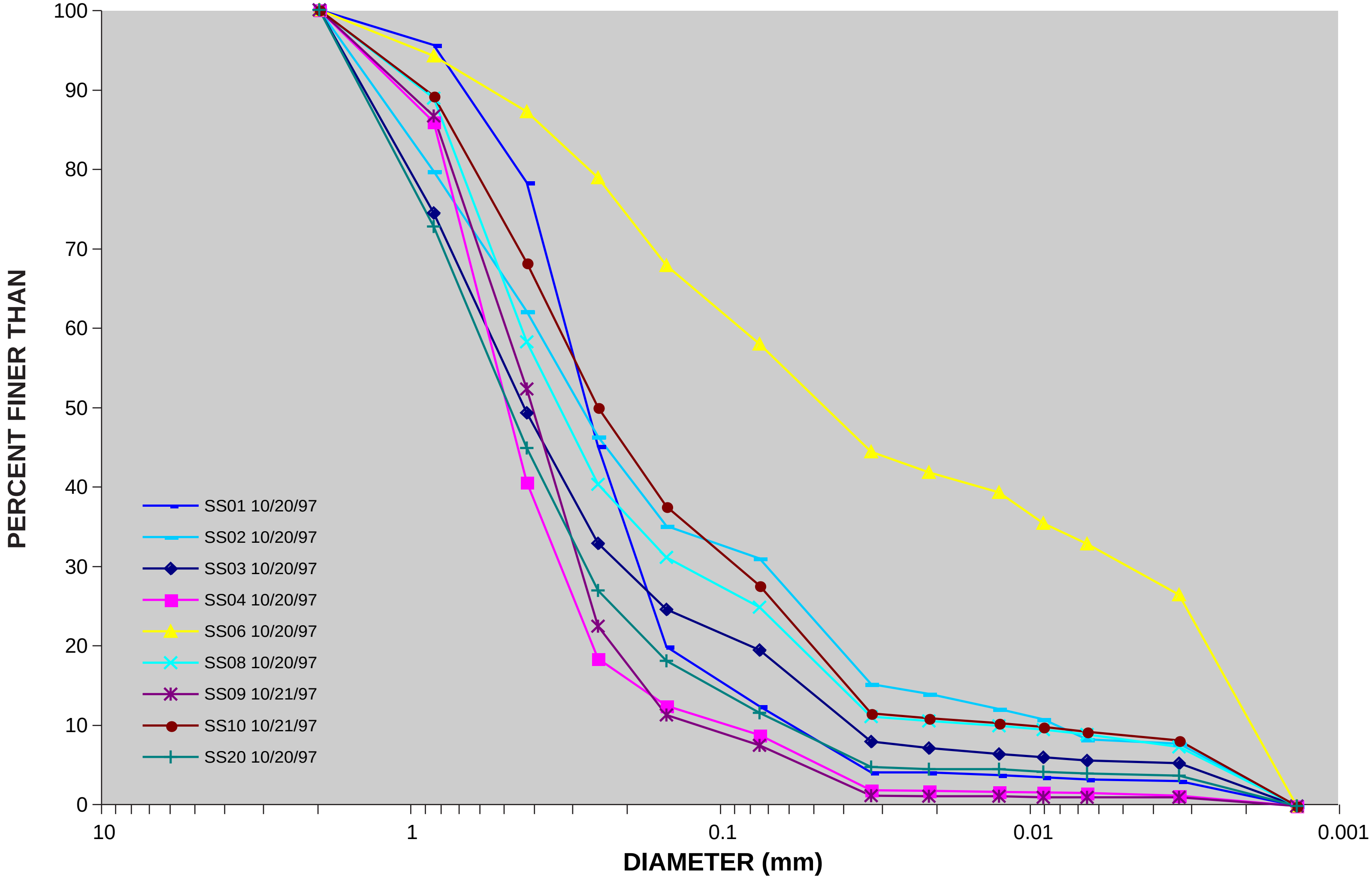


Figure C-3. Grain size distribution curves for 1997 CDM surface samples

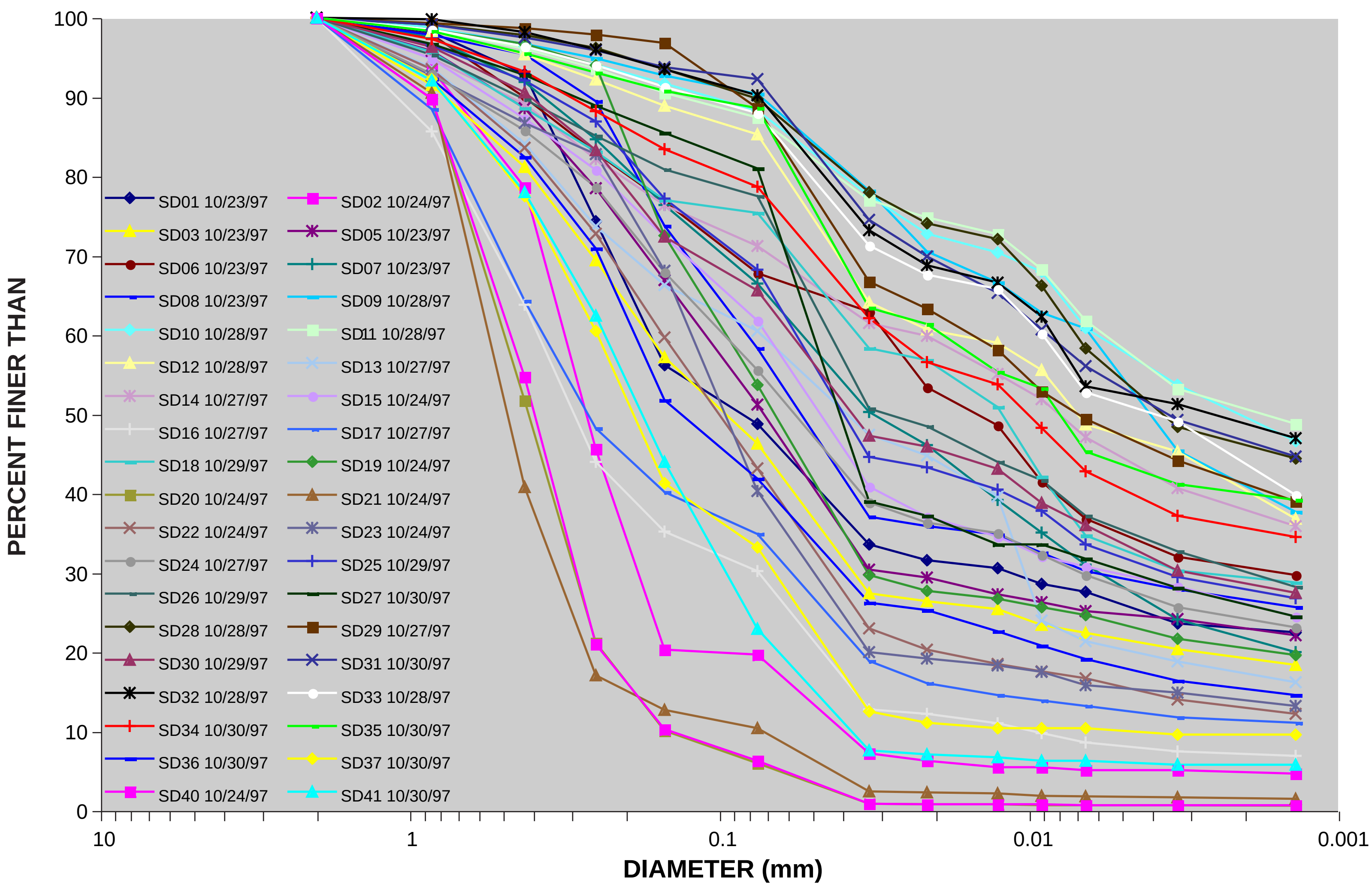


Figure C-4. Grain size distribution curves for 1997 CDM sediment samples

BE02578.001 1104 07/30/07 WA

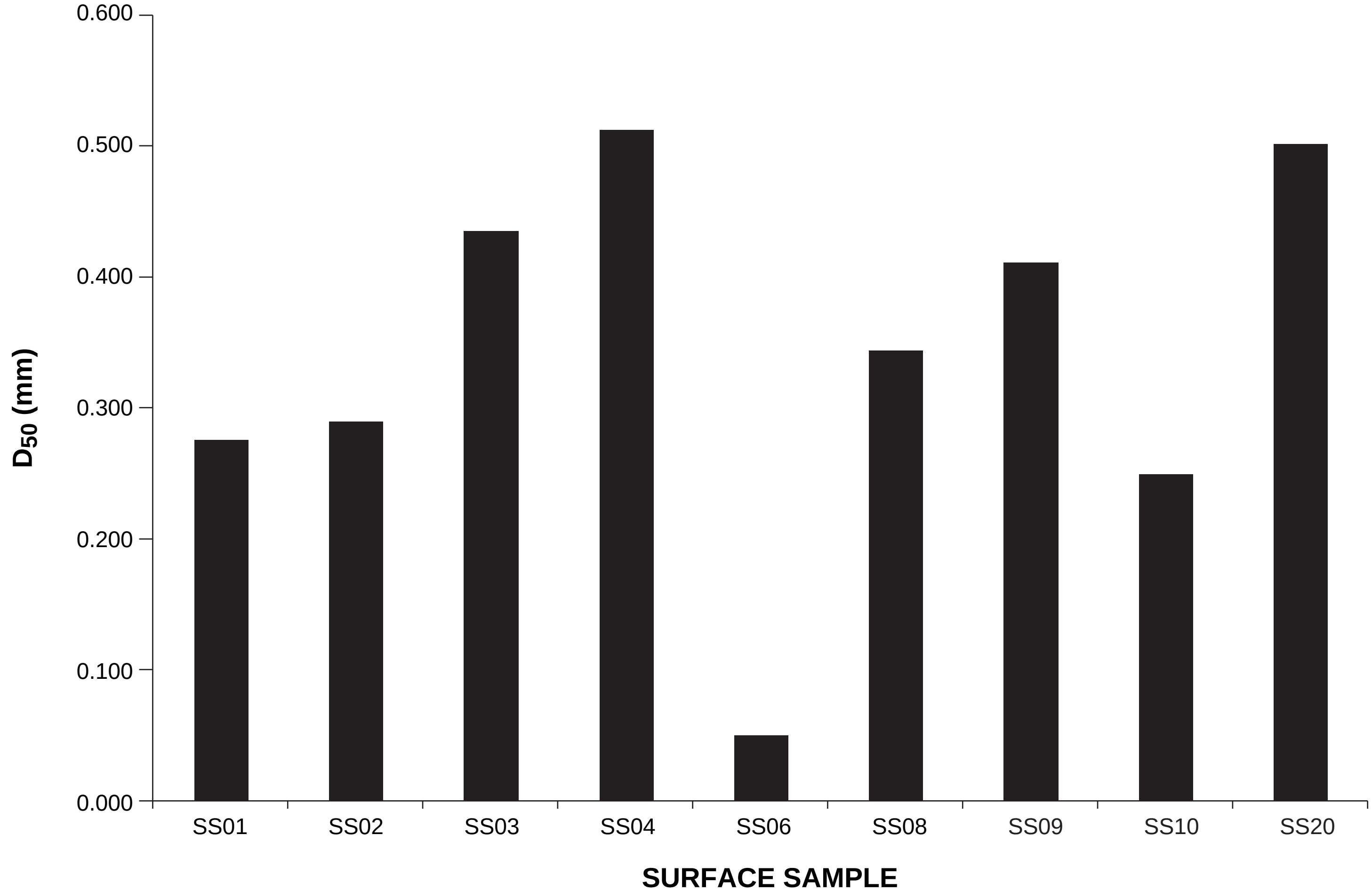


Figure C-5. CDM 1997 surface sample D_{50} values

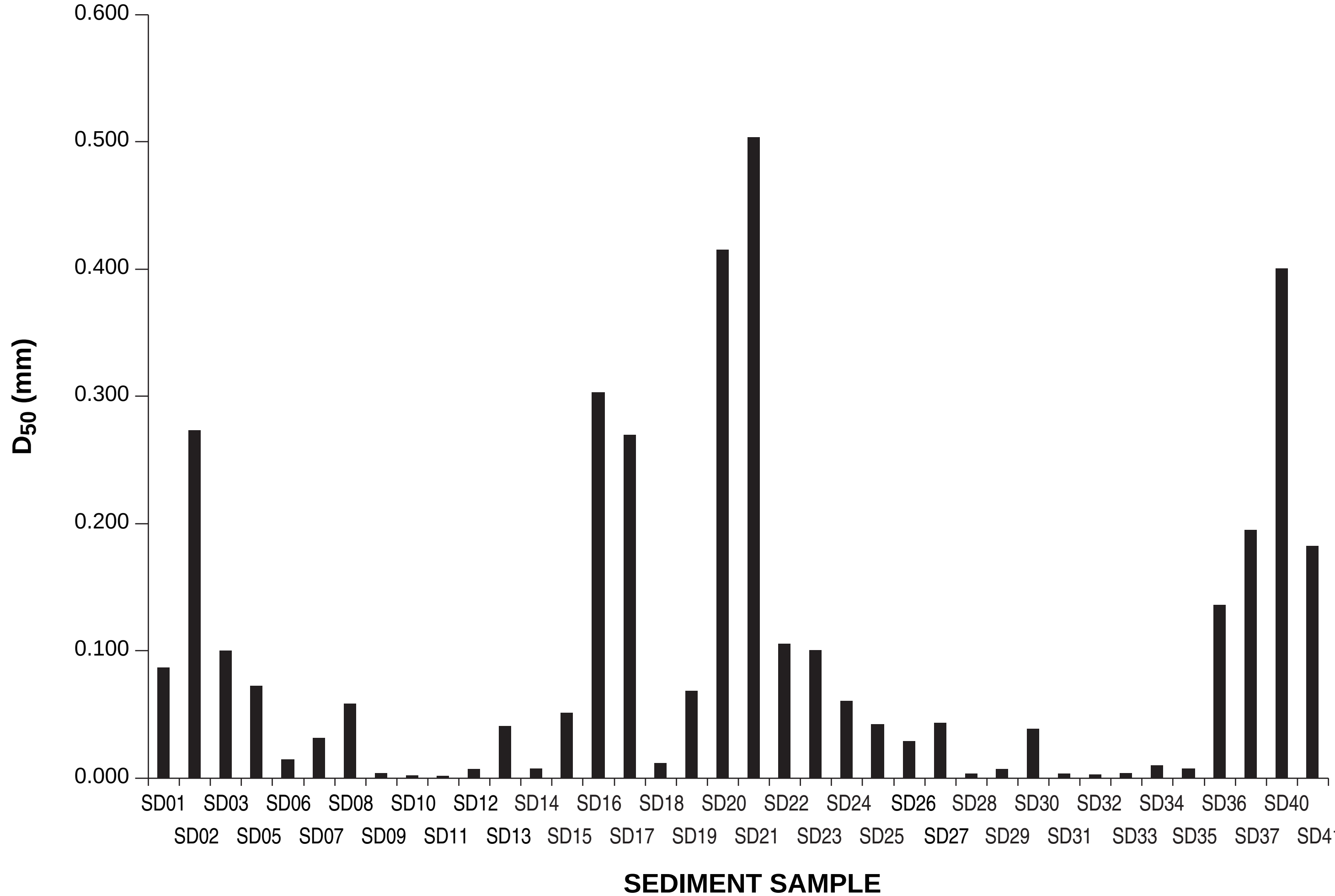


Figure C-6. CDM 1997 sediment sample D_{50} value

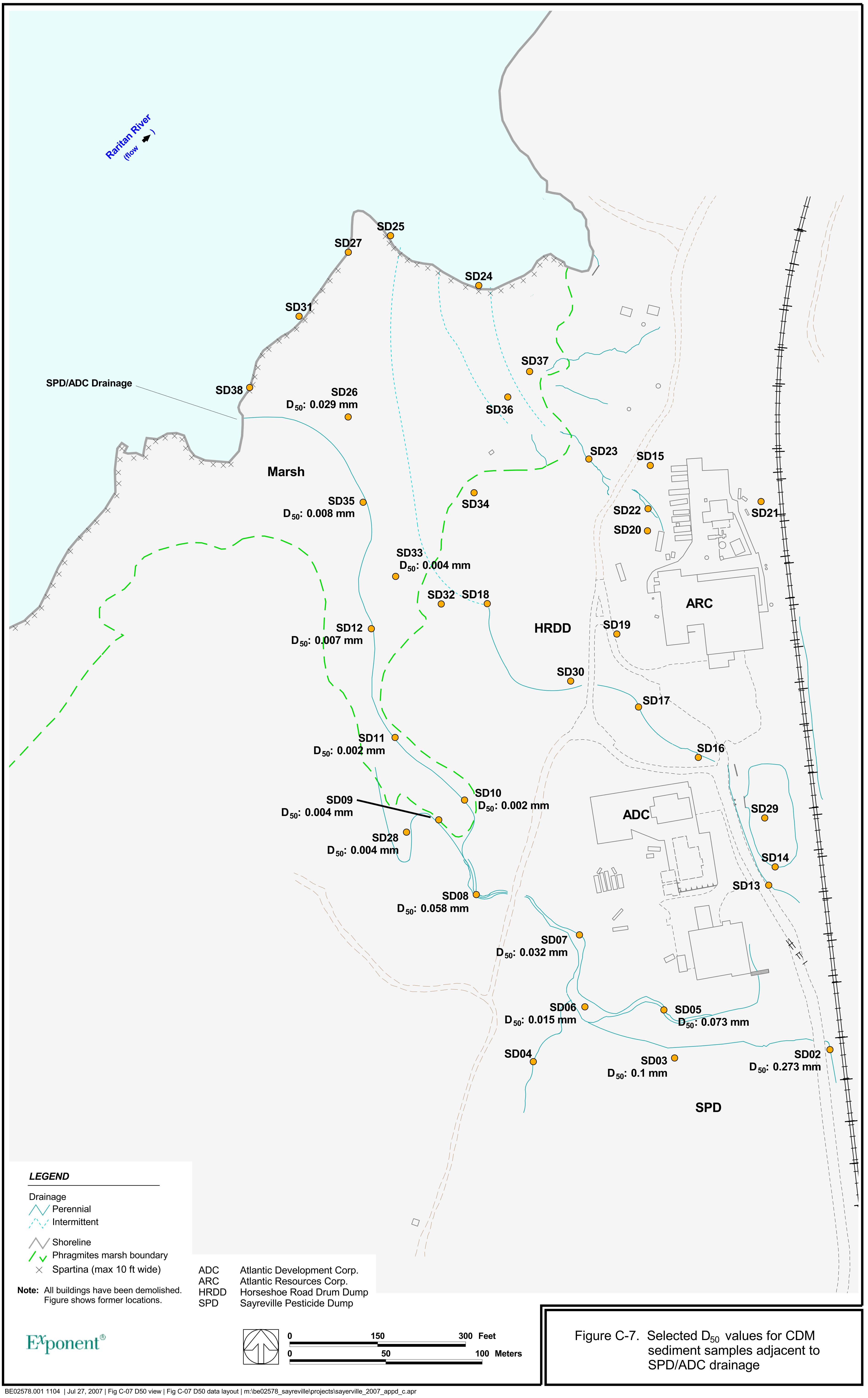


Figure C-7. Selected D_{50} values for CDM sediment samples adjacent to SPD/ADC drainage

BE02578.001 1104 | Jul 27, 2007 | Fig C-07 D50 view | Fig C-07 D50 data layout | m:\be02578_sayreville\projects\sayerville_2007_appd_c.apr

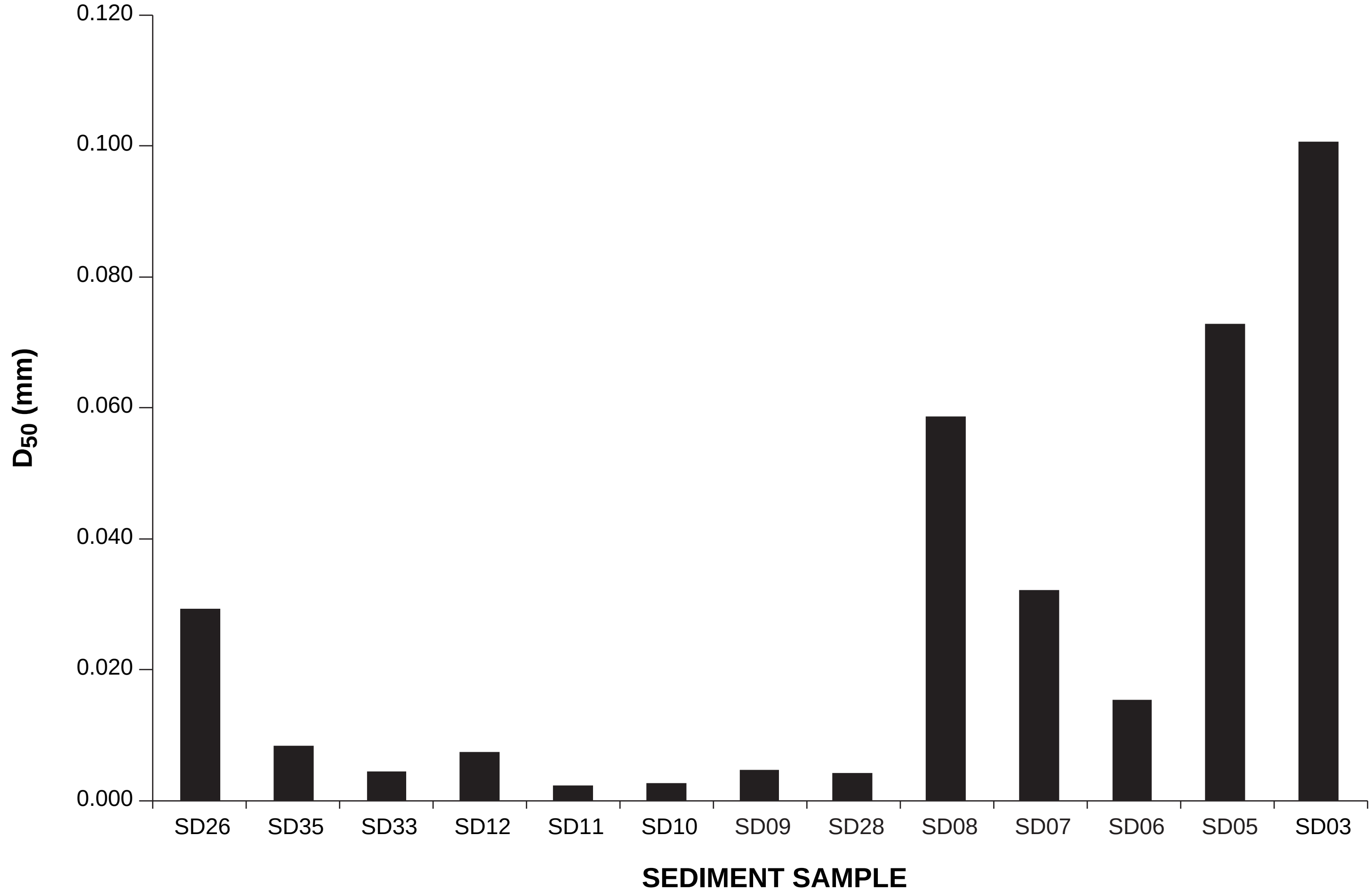
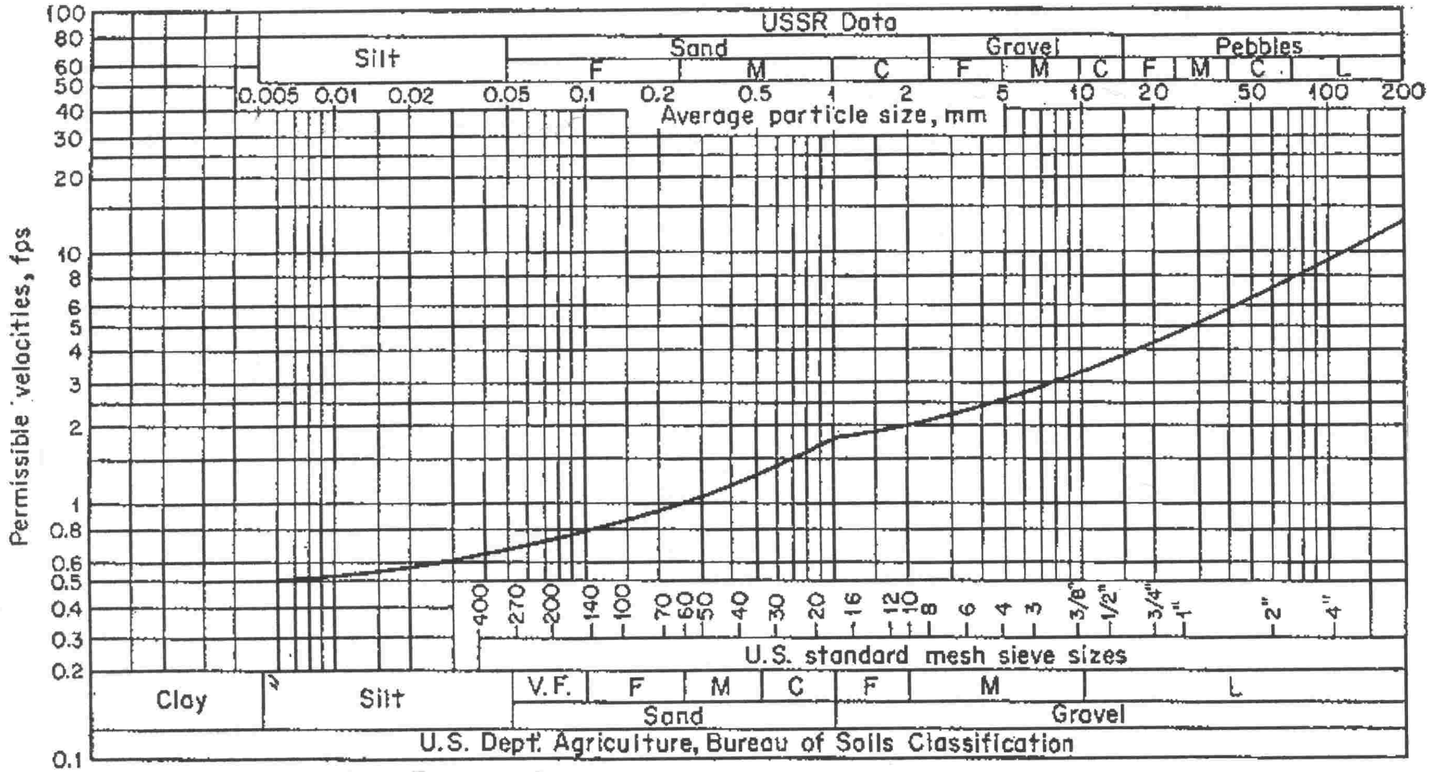


Figure C-8. CDM 1997 sediment sample D_{50} value along OU-3 channel and tributaries from downstream to upstream



Source: Chow (1959)

LEGEND

V.F. very fine
F fine
M medium
C caorse
L large

Figure C-9. U.S. and U.S.S.R data on permissable velocities for noncohehesive soils

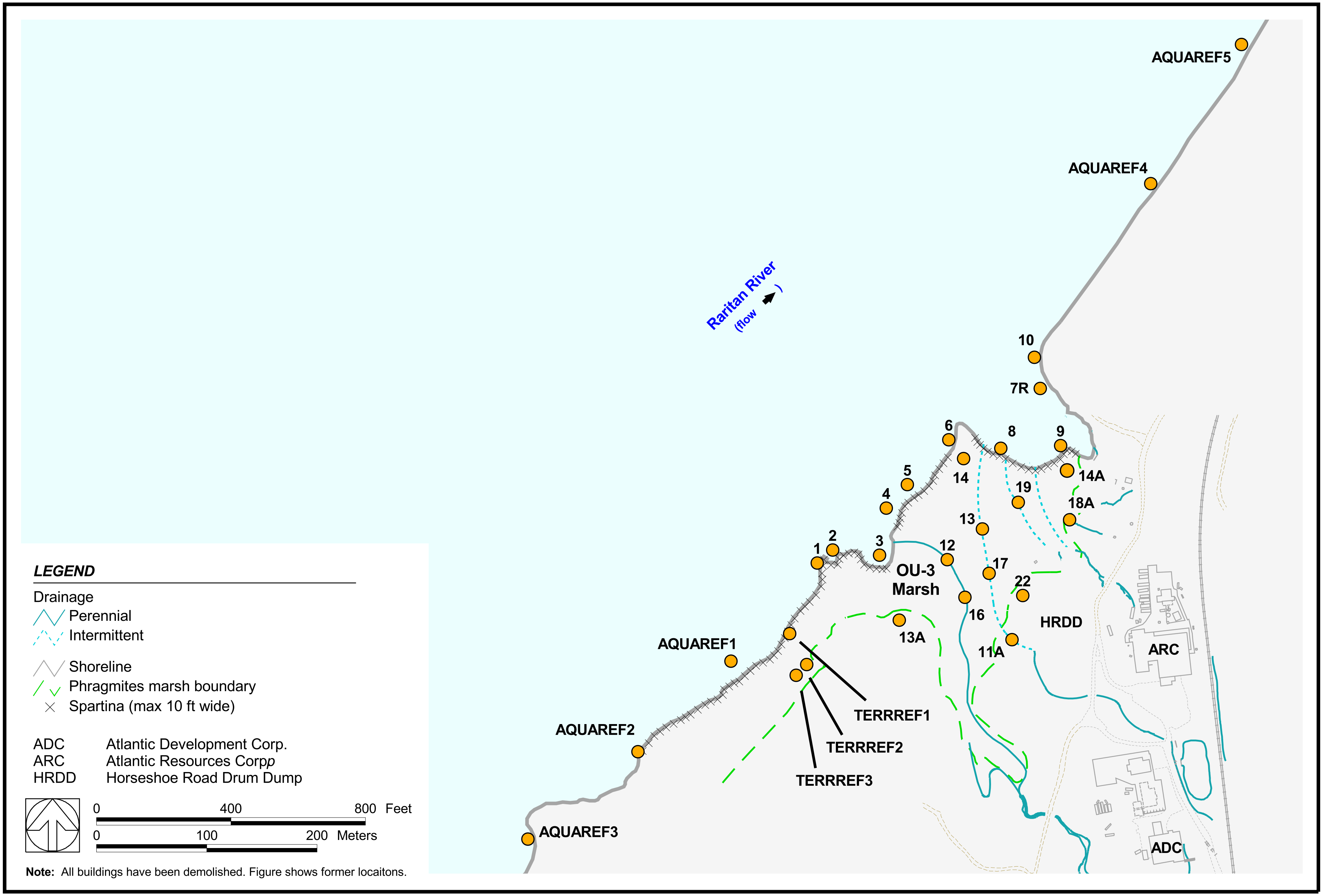


Figure C-10. Exponent 2004 soil sampling locations from OU-3 river and marsh area

Exponent®

BE02578.001 1104 | Jul 27, 2007 | Fig C-10 exp sampled loc view | Fig C-10 Exp sample loc layout | m:\be02578_sayreville\projects\sayerville_2007_appd_c.apr

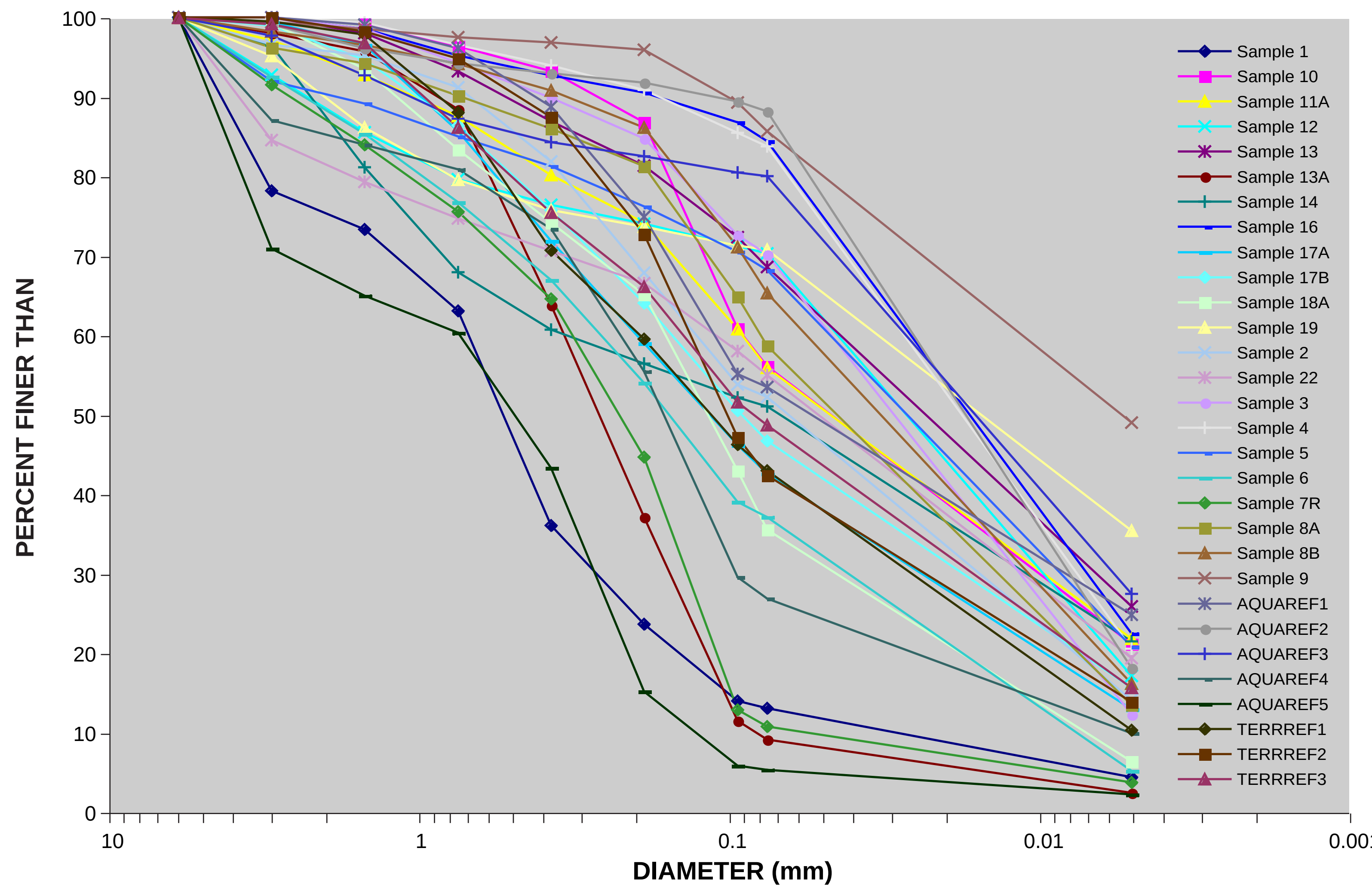


Figure C-11. Particle size distributioncurves for Exponent 2004 soil sampling

BE02578.001 1104 07/30/07 WA

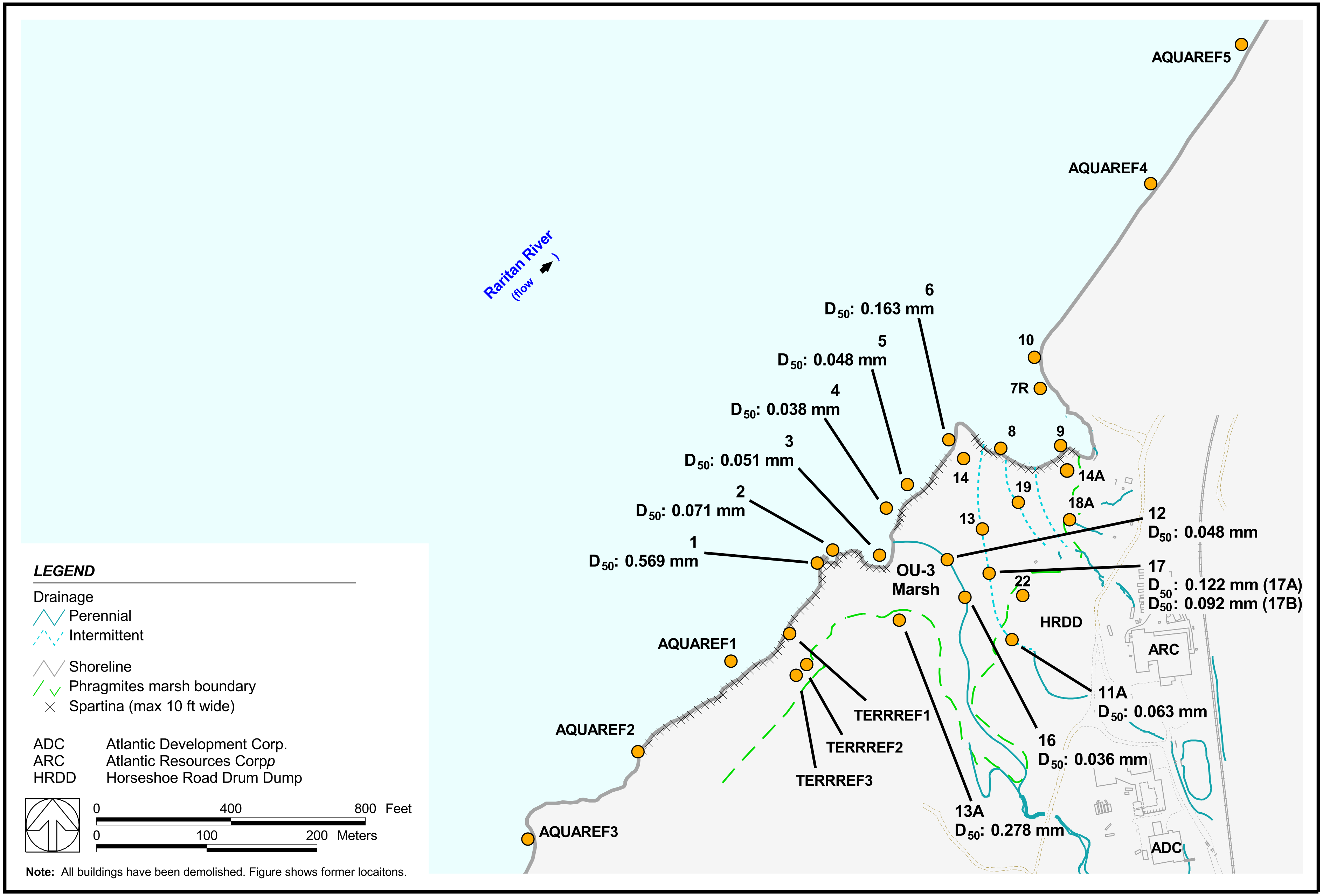


Figure C-12. Selected D_{50} values for Exponent 2004 soil sampling locations in OU-3 river and marsh area

Exponent®

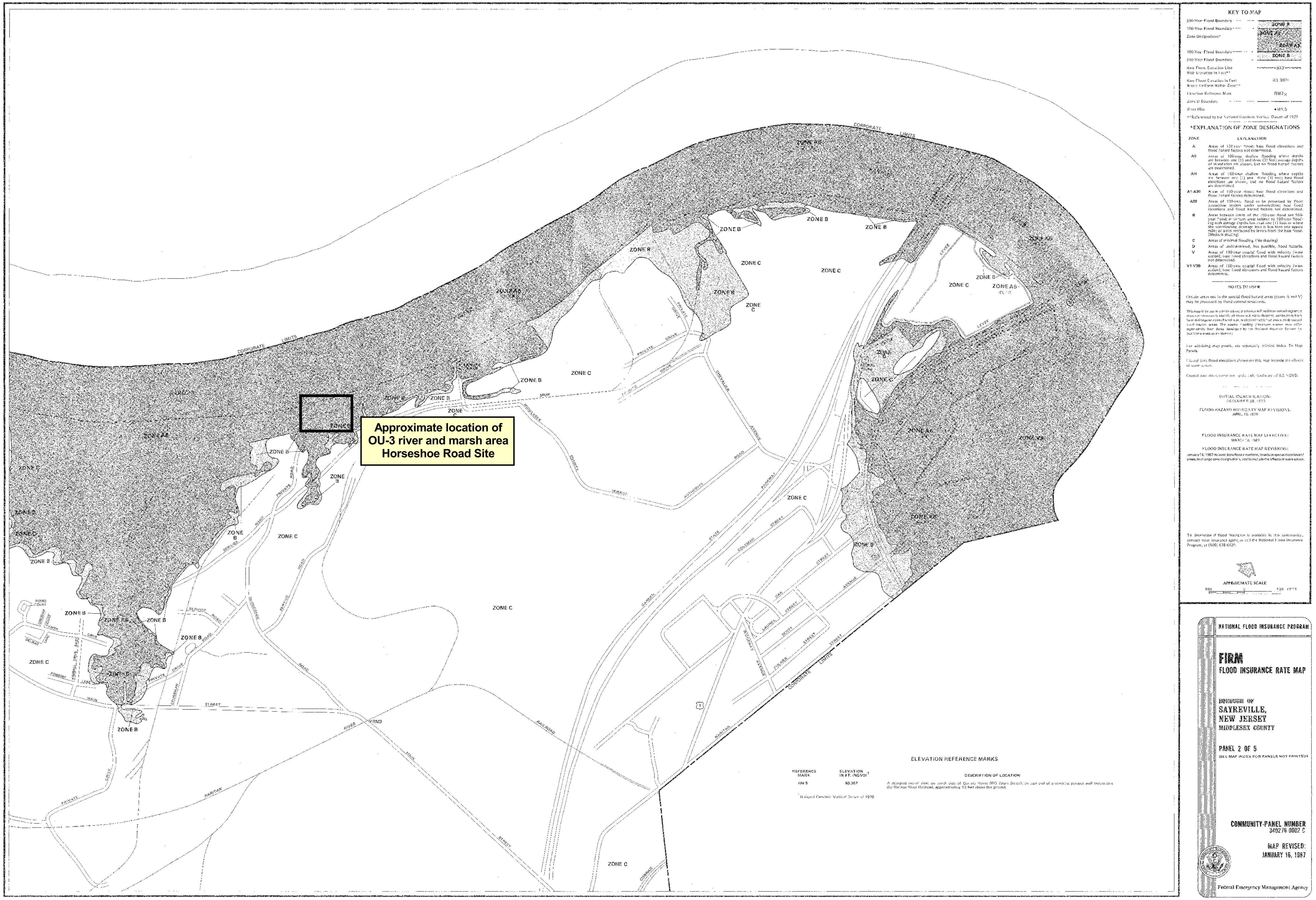


Figure C-13. FEMA FIRM for Sayreville, NJ Plate 2 of 5 with approximate location of OU-3 river and marsh

Exponent®

Source: Base map from USGS 7.5 miute topographic New Jersey maps South Amboy (1981) and Perth Amboy (1981).

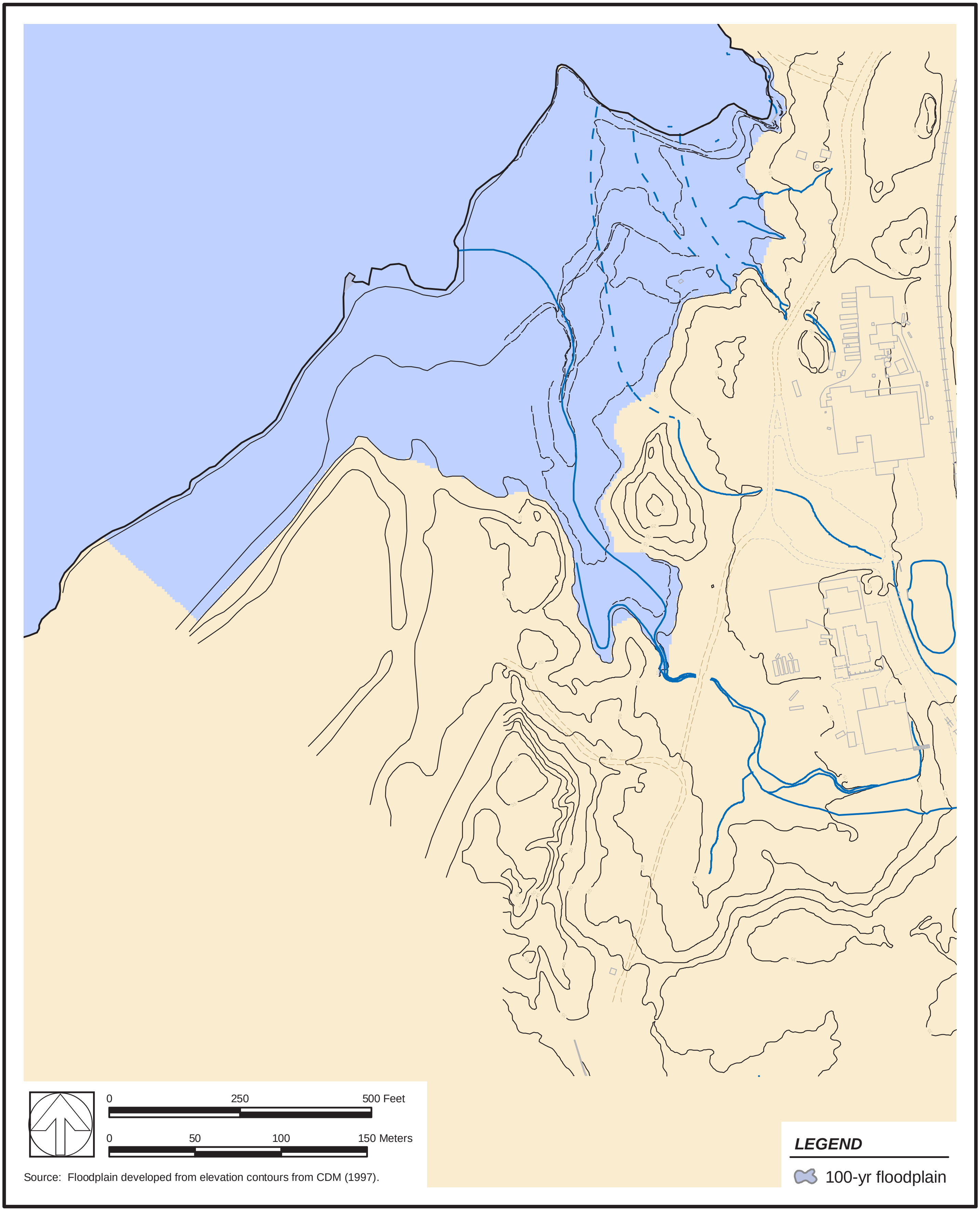
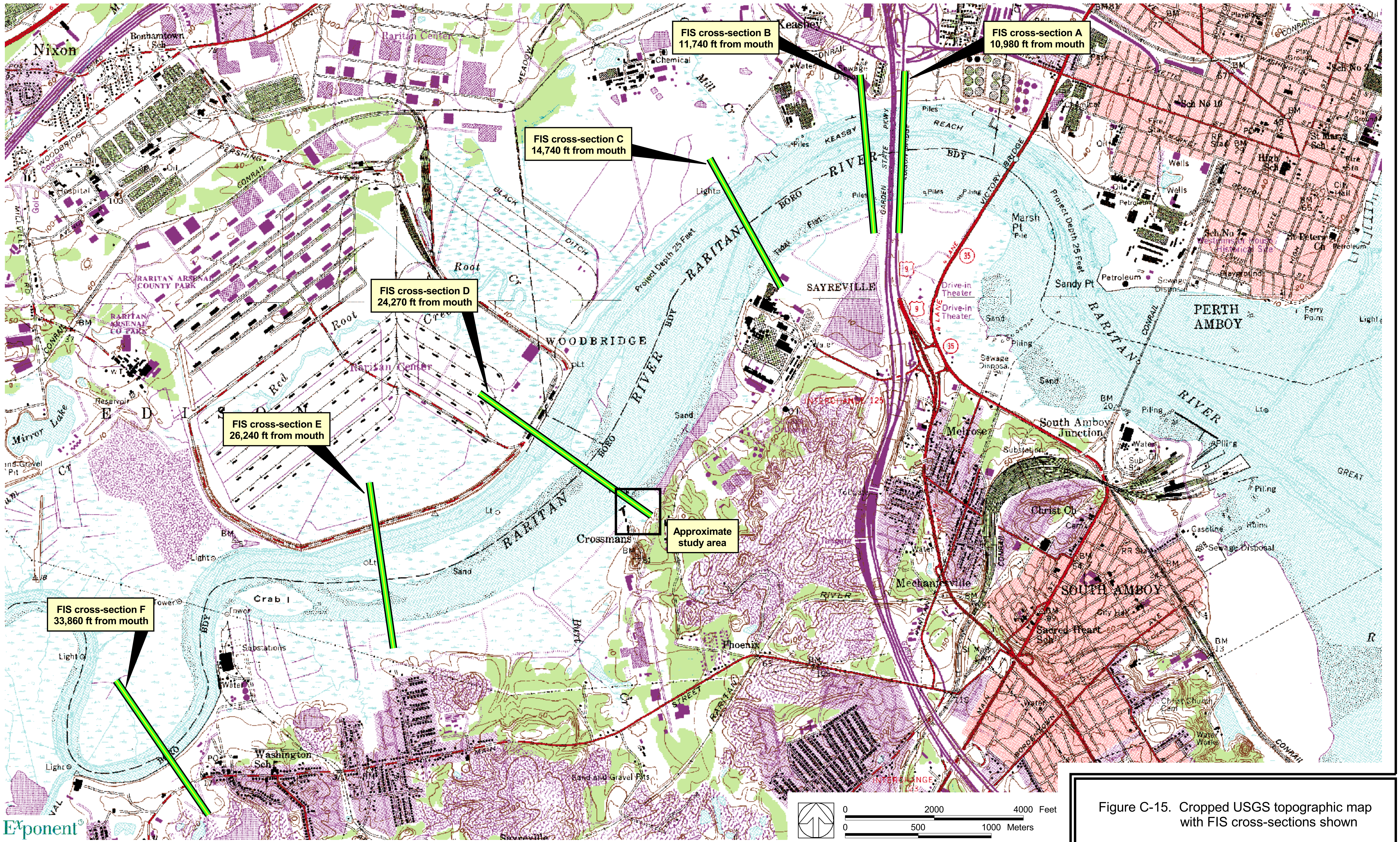


Figure C-14. Approximate 100-year floodplain in vicinity of project site based on elevation contours from CDM. Extent of delineated area limited to areas with known topography.

Exponent®



Source: Base map from USGS 7.5 miute topographic New Jersey maps South Amboy (1981) and Perth Amboy (1981).

Figure C-15. Cropped USGS topographic map with FIS cross-sections shown

BE02578 | Jul 30,2007 | Fig C-15 view | Fig C-15 FIS xsection layout | m:/be02578_sayreville/projects/sayerville_2007_appd_c.apr

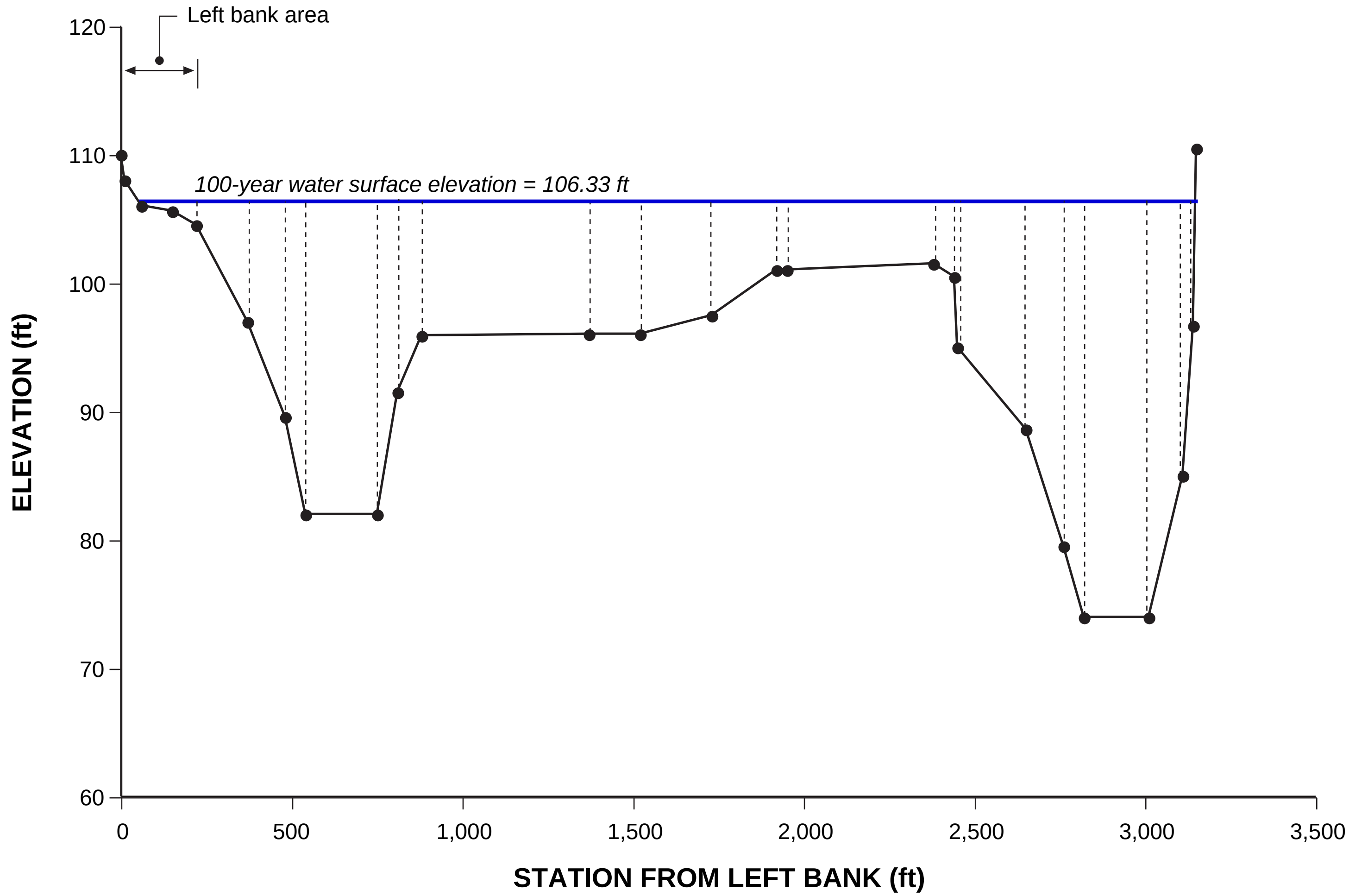
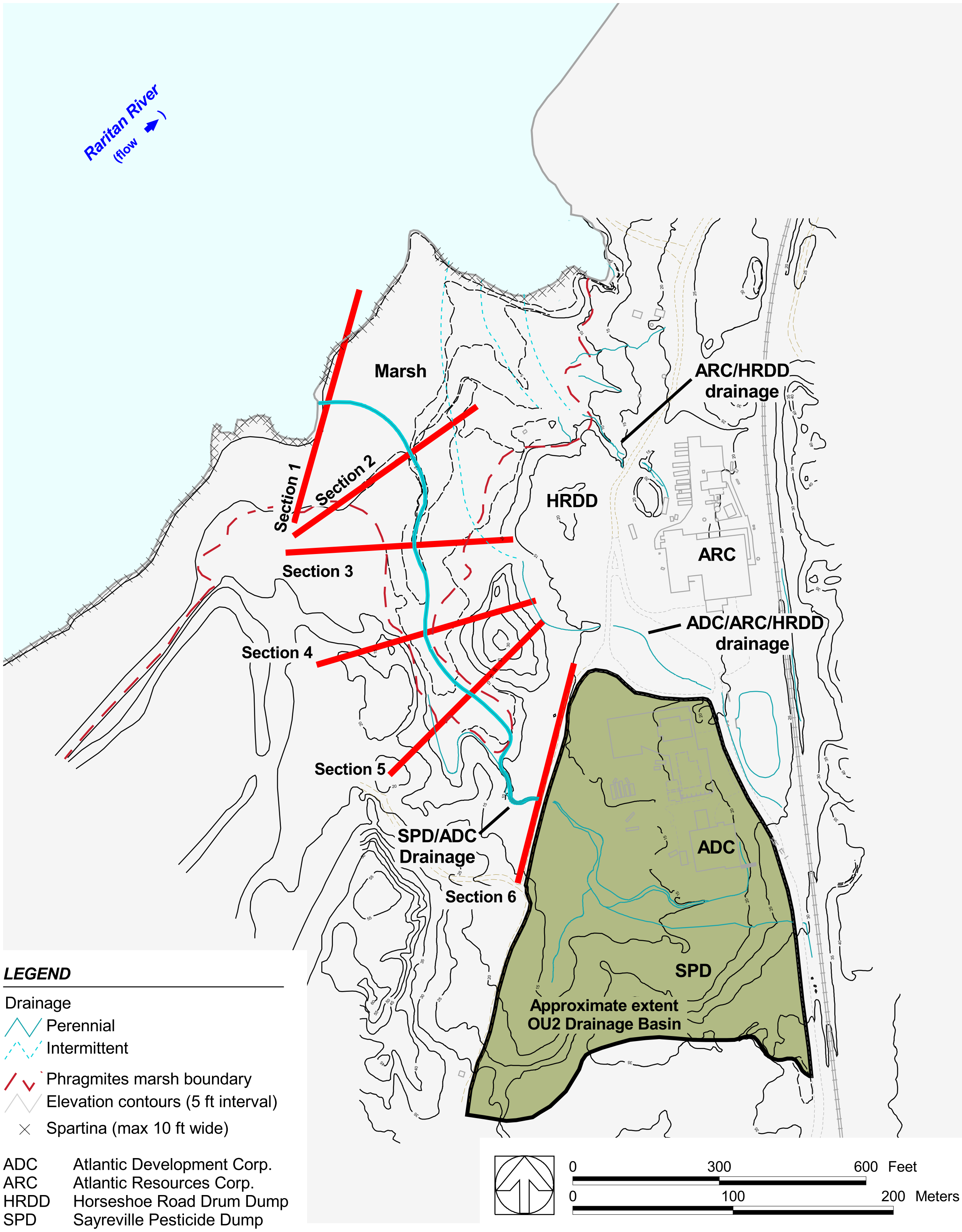


Figure C-16. Details of cross section D (looking upstream)

BE02578.001 1104 07/30/07 WA



Note: All buildings have been demolished. Figure shows former locations.

Figure C-17. Location of HEC-RAS cross-sections

Exponent®

BE02758.001 1004 | Feb 19, 2008 | Fig 1-2 Site detials view | ADC/SPD drainage overview layout | M:/BE02578_Sayreville/projects/sayreville_2008_env.apr

Tables

Table C-1. CDM 1997 surface sample grain size distribution data

	Sample								
	SS01	SS02	SS03	SS04	SS06	SS08	SS09	SS10	SS20
Particle Size mm	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing
0.00136	0	0	0	0	0	0	0	0	0
0.00329	3.1	7.8	5.4	1.3	26.5	7.4	1.1	8.2	3.8
0.00651	3.3	8.4	5.7	1.6	32.9	9	1.1	9.3	4.1
0.00904	3.6	10.9	6.1	1.7	35.5	9.6	1.1	9.9	4.3
0.01254	3.9	12.2	6.5	1.8	39.4	10.1	1.2	10.4	4.6
0.02121	4.2	14.1	7.3	1.9	41.9	10.7	1.2	11	4.6
0.0326	4.2	15.3	8.1	2	44.5	11.2	1.3	11.6	4.9
0.075	12.5	31.1	19.6	8.9	58	25	7.6	27.7	11.7
0.15	20	35.2	24.7	12.6	67.9	31.2	11.4	37.6	18.2
0.25	45.2	46.4	33	18.5	78.9	40.4	22.6	50.1	27.1
0.425	78.3	62.1	49.4	40.7	87.2	58.3	52.4	68.2	45
0.85	95.6	79.7	74.5	85.9	94.2	88.9	86.7	89.2	72.8
2	100	100	100	100	100	100	100	100	100

Table C-2. CDM 1997 sediment sample grain size distribution data

	Sample									
	SD01	SD02	SD03	SD04	SD05	SD06	SD07	SD08	SD09	SD10
mm	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer
0.00136	22.5	4.7	18.4	55.5	22.1	29.7	20	25.7	37.7	46.6
0.00329	23.6	5.1	20.4	62	24.2	32	24.1	27.9	45.4	53.7
0.00651	27.6	5.1	22.4	70.7	25.2	36.8	31	30.2	60.8	60.9
0.00904	28.6	5.5	23.4	77.2	26.3	41.5	35.1	32.5	62.8	68
0.01254	30.6	5.5	25.4	83.8	27.3	48.6	39.2	34.8	66.6	70.4
0.02121	31.6	6.3	26.4	90.3	29.4	53.4	46.1	35.9	70.5	72.8
0.0326	33.6	7.2	27.4	94.6	30.4	62.9	50.3	37.1	78.2	77.6
0.0750	48.8	19.7	46.3	90.8	51.2	67.8	66.5	58.3	90.4	88.3
0.1500	56.2	20.3	57.2	91.2	66.9	76.8	76.4	73.8	92.7	91.7
0.2500	74.3	45.6	69.4	94	78.5	83	84.7	89.5	94.9	94.1
0.4250	92.9	78.6	81.2	96.6	88.6	90	91.9	95.4	96.7	96.4
0.8500	98.2	93.5	91.5	98.9	95.8	97.9	97.5	97.8	98.7	98.8
2.0000	100	100	100	100	100	100	100	100	100	100

Table C-2. (cont.)

	Sample									
	SD11	SD12	SD13	SD14	SD15	SD16	SD17	SD18	SD19	SD20
mm	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer	Cumulative % Finer
0.00136	48.8	36.8	16.2	35.9	24.5	6.9	11.1	28.8	19.6	0.6
0.00329	53.2	45.3	18.8	40.7	28.3	7.5	11.8	30.3	21.7	0.7
0.00651	61.8	48.7	21.4	47.1	30.8	8.6	13.2	34.7	24.7	0.7
0.00904	68.3	55.6	24	51.9	32.1	9.8	13.9	42.1	25.7	0.7
0.01254	72.7	59	39.6	55.1	34.6	11	14.6	50.9	26.7	0.8
0.02121	74.8	60.7	44.8	59.9	37.1	12.2	16.1	56.8	27.7	0.8
0.0326	77	64.1	47.4	61.5	40.9	12.8	18.9	58.3	29.7	0.9
0.0750	87.4	85.3	60.5	71.2	61.8	30.2	34.9	75.4	53.7	6
0.1500	90.5	88.9	66.3	76.4	72.4	35.2	40.2	77	72.5	10.1
0.2500	93.6	92.2	73.7	82.2	80.8	44	48.2	83.1	94	21.2
0.4250	96.1	95.4	84.1	89.1	87.3	63.8	64.3	88.6	96.7	51.7
0.8500	98.5	98.3	93.7	94.9	94.8	85.7	88.5	95.7	98.5	89.8
2.0000	100	100	100	100	100	100	100	100	100	100

Table C-2. (cont.)

	Sample									
mm	SD21 Cumulative % Finer	SD22 Cumulative % Finer	SD23 Cumulative % Finer	SD24 Cumulative % Finer	SD25 Cumulative % Finer	SD26 Cumulative % Finer	SD27 Cumulative % Finer	SD28 Cumulative % Finer	SD29 Cumulative % Finer	SD30 Cumulative % Finer
0.00136	1.5	12.2	13.2	23.1	26.8	28.2	24.5	44.4	39	27.5
0.00329	1.7	14	14.9	25.7	29.5	32.7	28.1	48.4	44.2	30.3
0.00651	1.8	16.7	15.8	29.7	33.6	37.2	31.8	58.3	49.4	36
0.00904	1.9	17.6	17.5	32.3	37.8	41.7	33.6	66.2	52.9	38.8
0.01254	2.2	18.5	18.3	35	40.5	44	33.6	72.1	58.1	43.1
0.02121	2.3	20.3	19.2	36.3	43.3	48.5	37.2	74.1	63.3	45.9
0.0326	2.4	23	20	38.9	44.6	50.7	39	78	66.7	47.3
0.0750	10.4	43.2	40.3	55.6	68.2	77.5	81	89.8	88.6	65.6
0.1500	12.7	59.7	68.1	67.9	77.2	80.9	85.5	93.5	96.8	72.4
0.2500	17.1	72.8	82.8	78.6	86.9	85.1	88.9	96.2	97.9	83.3
0.4250	40.8	83.6	86.7	85.8	92.1	89.7	92.8	97.8	98.7	90.6
0.8500	90.5	93.5	92.7	92.9	96.5	95.3	96.7	99.1	99.3	96.3
2.0000	100	100	100	100	100	100	100	100	100	100

Table C-2. (cont.)

	Sample								
	SD31	SD32	SD33	SD34	SD35	SD36	SD37	SD40	SD41
	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative	Cumulative
mm	% Finer	% Finer	% Finer	% Finer	% Finer	% Finer	% Finer	% Finer	% Finer
0.00136	44.7	47	39.8	34.5	39.2	14.6	9.6	0.7	5.8
0.00329	49.3	51.3	49.1	37.2	41.2	16.4	9.6	0.7	5.8
0.00651	56.1	53.5	52.8	42.8	45.3	19.1	10.4	0.7	6.3
0.00904	60.7	62.3	60.2	48.3	53.3	20.8	10.4	0.8	6.3
0.01254	65.3	66.6	65.8	53.8	55.3	22.6	10.4	0.8	6.7
0.02121	69.9	68.8	67.6	56.6	61.4	25.3	11.1	0.8	7.1
0.0326	74.5	73.2	71.3	62.1	63.4	26.2	12.5	0.9	7.6
0.0750	92.3	90.2	88	78.7	88.6	41.9	33.2	6.3	22.9
0.1500	93.8	93.5	91.3	83.4	90.8	51.8	41.3	10.3	44
0.2500	95.9	96	94	88.2	93.1	70.9	60.5	21	62.4
0.4250	97.5	98.2	96.4	93.2	95.5	82.4	77.5	54.7	78
0.8500	99.1	99.8	98.5	97.3	98.3	92.3	92.3	89.8	92.1
2.0000	100	100	100	100	100	100	100	100	100

Table C-3. CDM 1997 surface samples: D_{50}, classification and permissible velocity

Sample Code	D_{50} (mm)	Classification	Permissible Velocity (fps)
SS01	0.275	Fine Sand	1.06
SS02	0.29	Fine Sand	1.09
SS03	0.435	Medium Sand	1.24
SS04	0.512	Medium Sand	1.31
SS06	0.05	Silt	0.68
SS08	0.344	Fine Sand	1.14
SS09	0.411	Fine Sand	1.21
SS10	0.249	Fine Sand	1.02
SS20	0.501	Medium Sand	1.3

Table C-4. CDM 1997 sediment samples: D_{50}, classification and permissible velocity

Sample Code	D_{50} (mm)	Classification	Permissible Velocity (fps)
SD01	0.087	Fine Sand	0.77
SD02	0.273	Fine Sand	1.06
SD03	0.1	Fine Sand	0.8
SD04	Discard	Discard	Discard
SD05	0.073	Silt	0.75
SD06	0.015	Silt	0.56
SD07	0.032	Silt	0.61
SD08	0.058	Silt	0.71
SD09	0.004	Clay	0.5
SD10	0.002	Clay	0.5
SD11	0.002	Clay	0.5
SD12	0.007	Silt	0.51
SD13	0.041	Silt	0.65
SD14	0.008	Silt	0.52
SD15	0.051	Silt	0.68
SD16	0.303	Fine Sand	1.1
SD17	0.27	Fine Sand	1.05
SD18	0.012	Silt	0.55
SD19	0.068	Silt	0.74
SD20	0.415	Fine Sand	1.22
SD21	0.504	Medium Sand	1.3
SD22	0.106	Fine Sand	0.81
SD23	0.101	Fine Sand	0.8
SD24	0.061	Silt	0.72
SD25	0.042	Silt	0.66
SD26	0.029	Silt	0.6
SD27	0.044	Silt	0.66
SD28	0.004	Clay	0.5
SD29	0.007	Silt	0.51
SD30	0.039	Silt	0.64
SD31	0.004	Clay	0.5
SD32	0.003	Clay	0.5
SD33	0.004	Clay	0.5
SD34	0.01	Silt	0.54
SD35	0.008	Silt	0.52
SD36	0.136	Fine Sand	0.86
SD37	0.195	Fine Sand	0.94
SD40	0.401	Fine Sand	1.2
SD41	0.183	Fine Sand	0.93

Table C-5. Exponent 2004 soil sampling grain size distribution data

Survey station:	18A	19	2	22	3	4	5	6	7R
Average grain size (mm):	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing	Cumulative % Passing
0.005	6.2	35.4	14	19.3	12.2	20.4	20.8	5.1	3.6
0.075	35.4	70.7	52.2	55	70.1	83.7	68.2	37.1	10.7
0.09375	42.9	71.3	53.8	58	72.6	85.5	70.5	39	12.7
0.1875	65.1	73.6	67.8	66.5	84.8	90.8	76.2	53.9	44.6
0.375	74.1	75.7	81.8	70.6	89.8	94	81.2	66.9	64.5
0.75	83.4	79.6	91.2	74.6	94.3	96.5	85	76.7	75.5
1.5	93.5	86.1	95.2	79.3	98.6	99.3	89.1	85.3	84
3	99.3	95.1	96.6	84.6	100	100	92	92.5	91.5
6	100	100	100	100	100	100	100	100	100

Table C-5. (cont.)

Survey station: Average grain size (mm):	8A Cumulative % Passing	8B Cumulative % Passing	9 Cumulative % Passing	AQUAREF1 Cumulative % Passing	AQUAREF2 Cumulative % Passing	AQUAREF3 Cumulative % Passing	AQUAREF4 Cumulative % Passing	AQUAREF5 Cumulative % Passing	TERRREF1 Cumulative % Passing	TERRREF2 Cumulative % Passing	TERRREF3 Cumulative % Passing
0.005	13.4	16.1	48.9	24.7	18	27.3	9.8	2.1	10.2	13.8	15.5
0.075	58.6	65.3	85.6	53.4	88.2	80	26.7	5.2	42.9	42.3	48.6
0.09375	64.8	71.1	89.3	55.1	89.4	80.5	29.4	5.7	46.2	47.1	51.5
0.1875	81.3	86.1	95.9	74.9	91.8	82.5	55.4	15.1	59.4	72.7	66.1
0.375	86	90.8	96.8	88.7	93	84.3	73.4	43.2	70.7	87.4	75.4
0.75	90.1	94.2	97.5	96.1	94.2	87.2	80.8	60.3	88	94.8	86.1
1.5	94.2	96.5	98.5	99.1	96.1	92.7	83.9	64.9	97.9	98.2	96.8
3	96.2	98.2	99.4	100	99.1	97.7	87	70.8	99.5	100	99.1
6	100	100	100	100	100	100	100	100	100	100	100

Table C-6. Exponent 2004 soil samples: D_{50}, classification and permissible velocity

Survey station:	D_{50} (mm)	Classification	Permissible Velocities (fps)
1	0.569	Medium Sand	1.37
10	0.063	Silt	0.73
11A	0.063	Silt	0.73
12	0.048	Silt	0.67
13	0.045	Silt	0.66
13A	0.278	Fine Sand	1.07
14	0.073	Silt	0.75
16	0.036	Silt	0.63
17A	0.122	Fine Sand	0.84
17B	0.092	Fine Sand	0.78
18A	0.124	Fine Sand	0.84
19	0.034	Silt	0.62
2	0.071	Silt	0.74
22	0.065	Silt	0.73
3	0.051	Silt	0.68
4	0.038	Silt	0.64
5	0.048	Silt	0.67
6	0.163	Fine Sand	0.9
7R	0.238	Fine Sand	1.01
8A	0.062	Silt	0.72
8B	0.053	Silt	0.69
9	0.007	Silt	0.52
AQUAREF1	0.067	Silt	0.73
AQUAREF2	0.037	Silt	0.63
AQUAREF3	0.035	Silt	0.63
AQUAREF4	0.168	Fine Sand	0.91
AQUAREF5	0.524	Medium Sand	1.32
TERRREF1	0.121	Fine Sand	0.83
TERRREF2	0.104	Fine Sand	0.81
TERRREF3	0.084	Fine Sand	0.77

Table C-7. FEMA FIS floodway mean velocities for cross-sections along the Raritan River (data taken from FEMA FIS, 1987)

Cross-Section	Distance from Mouth of Raritan River (ft)	Width (ft)	Width within Corporate Limits (ft)	Section Area (ft^2)	Mean Velocity (fps)
A	10,980	2,110	1,020	33,860	1.8
B	11,740	1,980	1,070	33,950	1.8
C	14,740	1,870	930	39,420	1.6
D	21,270	2,840	1,165	39,130	1.6
E	26,240	2,430	1,060	26,410	2.4
F	33,860	5,700	270	29,890	2

Table C-8. FEMA FIS peak discharges at select cross-sections (data taken from FEMA FIS, 1987)

Location	Drainage Area (mi^2)	Peak Discharges (cfs)			
		10-year	50-year	100-year	500-year
Downstream Corporate Limits of Raritan River	1,093	43,600	54,170	62,090	80,590
Raritan River at the Washington Canal	1,072	42,820	53,210	60,990	79,160

Table C-9. CDM surface sample D50, corresponding soil type, and permissible belocities

Sample Code	D_{50} (mm)	Classification	Permissible Velocity (fps)
CDM Sediment Samples			
SD08	0.058	Silt	0.71
SD09	0.004	Clay	0.50
SD10	0.002	Clay	0.50
SD11	0.002	Clay	0.50
SD12	0.007	Silt	0.51
SD26[a]	0.029	Silt	0.60
SD28[a]	0.004	Clay	0.50
SD33[a]	0.004	Clay	0.50
SD35	0.008	Silt	0.52
Exponent Soil Samples			
12	0.048	Silt	0.67
13A[a]	0.278	Fine Sand	1.07
16	0.036	Silt	0.63
3	0.051	Silt	0.68

[a] Adjacent to SPD/ADC drainage channel.

Table C-10. Channel and overbank velocities calculated by the HEC-RAS model

	Calculated Velocties		
River Station	Left Overbank (fps)	Channel Center (fps)	Right Overbank (fps)
6		2.38	
5	0.23	1.83	0.36
4	0.42	1.60	0.37
3	0.65	2.58	0.58
2	0.08	0.21	0.05
1	0.02	0.04	0.02

Attachment C-1

Grain Size Distribution

GRAIN SIZE DISTRIBUTION

(For sediment and surface soil - sitewide)

Horseshoe Road, Sayreville, New Jersey
Sediment Samples
Grain Size Distribution

Cas Rn	Chemical Name	Analytic Method	Sample Code / Sample Date / Sample Matrix / Unit \\ Parent	SD01 10/23/97 Sediment	SD02 10/24/97 Sediment	SD03 10/23/97 Sediment	SD04 10/24/97 Sediment	SD07 10/23/97 Sediment
(Group Code)	**(Group Description)**							
Grain	**Grain Size Distribution**							
01-CLAY	Percent less than sieve size 1.25 - 1.47	HYDRO	%	22.5	4.7	18.4	55.5	20
02-CLAY	Percent less than sieve size 3 - 3.57	HYDRO	%	1.1	0.4	2	6.5	4.1
03-SILT	Percent less than sieve size 5.89 - 7.13	HYDRO	%	4	0	2	8.7	6.9
04-SILT	Percent less than sieve size 8.06 - 10.02	HYDRO	%	1	0.4	1	6.5	4.1
05-SILT	Percent less than sieve size 10.95 - 14.13	HYDRO	%	2	0	2	6.6	4.1
06-SILT	Percent less than sieve size 17.94 - 24.47	HYDRO	%	1	0.8	1	6.5	6.9
07-SILT	Percent less than sieve size 26.65 - 38.55	HYDRO	%	2	0.9	1	4.3	4.2
08-SILT	Percent less than sieve size 75	GRAIN	%	15.2	12.5	18.9	-3.8	16.2
09-FINE-SAND	Percent less than sieve size 150	GRAIN	%	7.4	0.6	10.9	0.4	9.9
10-FINE-SAND	Percent less than sieve size 250	GRAIN	%	18.1	25.3	12.2	2.8	8.3
11-MEDIUM SAND	Percent less than sieve size 425	GRAIN	%	18.6	33	11.8	2.6	7.2
12-COARSE SAND	Percent less than sieve size 850	GRAIN	%	5.3	14.9	10.3	2.3	5.6
13-COARSE SAND	Percent less than sieve size 2000	GRAIN	%	1.8	6.5	8.5	1.1	2.5
Sum				100	100	100	100	100

Horseshoe Road, Sayreville, New Jersey
Sediment Samples
Grain Size Distribution

			Sample Code	SD05	SD06	SD08	SD09	SD10
			Sample Date	10/23/97	10/23/97	10/23/97	10/28/97	10/28/97
			Sample Matrix	Sediment	Sediment	Sediment	Sediment	Sediment
CasRn	Chemical Name	Analytic Method	Unit \\ Parent					
(Group Code)	**(Group Description)**							
Grain	**Grain Size Distribution**							
01-CLAY	Percent less than sieve size 1.25 - 1.47	HYDRO	%	22.1	29.7	25.7	37.7	46.6
02-CLAY	Percent less than sieve size 3 - 3.57	HYDRO	%	2.1	2.3	2.2	7.7	7.1
03-SILT	Percent less than sieve size 5.89 - 7.13	HYDRO	%	1	4.8	2.3	15.4	7.2
04-SILT	Percent less than sieve size 8.06 - 10.02	HYDRO	%	1.1	4.7	2.3	2	7.1
05-SILT	Percent less than sieve size 10.95 - 14.13	HYDRO	%	1	7.1	2.3	3.8	2.4
06-SILT	Percent less than sieve size 17.94 - 24.47	HYDRO	%	2.1	4.8	1.1	3.9	2.4
07-SILT	Percent less than sieve size 26.65 - 38.55	HYDRO	%	1	9.5	1.2	7.7	4.8
08-SILT	Percent less than sieve size 75	GRAIN	%	20.8	4.9	21.2	12.2	10.7
09-FINE-SAND	Percent less than sieve size 150	GRAIN	%	15.7	9	15.5	2.3	3.4
10-FINE-SAND	Percent less than sieve size 250	GRAIN	%	11.6	6.2	15.7	2.2	2.4
11-MEDIUM SAND	Percent less than sieve size 425	GRAIN	%	10.1	7	5.9	1.8	2.3
12-COARSE SAND	Percent less than sieve size 850	GRAIN	%	7.2	7.9	2.4	2	2.4
13-COARSE SAND	Percent less than sieve size 2000	GRAIN	%	4.2	2.1	2.2	1.3	1.2
Sum				100	100	100	100	100

Horseshoe Road, Sayreville, New Jersey
Sediment Samples
Grain Size Distribution

Cas Rn	Chemical Name	Analytic Method	Sample Code / Sample Date / Sample Matrix / Unit \\ Parent	SD11 10/28/97 Sediment	SD12 10/28/97 Sediment	SD13 10/27/97 Sediment	SD14 10/27/97 Sediment	SD15 10/24/97 Sediment
(Group Code)	**(Group Description)**							
Grain	**Grain Size Distribution**							
01-CLAY	Percent less than sieve size 1.25 - 1.47	HYDRO	%	48.8	36.8	16.2	35.9	24.5
02-CLAY	Percent less than sieve size 3 - 3.57	HYDRO	%	4.4	8.5	2.6	4.8	3.8
03-SILT	Percent less than sieve size 5.89 - 7.13	HYDRO	%	8.6	3.4	2.6	6.4	2.5
04-SILT	Percent less than sieve size 8.06 - 10.02	HYDRO	%	6.5	6.9	2.6	4.8	1.3
05-SILT	Percent less than sieve size 10.95 - 14.13	HYDRO	%	4.4	3.4	15.6	3.2	2.5
06-SILT	Percent less than sieve size 17.94 - 24.47	HYDRO	%	2.1	1.7	5.2	4.8	2.5
07-SILT	Percent less than sieve size 26.65 - 38.55	HYDRO	%	2.2	3.4	2.6	1.6	3.8
08-SILT	Percent less than sieve size 75	GRAIN	%	10.4	21.2	13.1	9.7	20.9
09-FINE-SAND	Percent less than sieve size 150	GRAIN	%	3.1	3.6	5.8	5.2	10.6
10-FINE-SAND	Percent less than sieve size 250	GRAIN	%	3.1	3.3	7.4	5.8	8.4
11-MEDIUM SAND	Percent less than sieve size 425	GRAIN	%	2.5	3.2	10.4	6.9	6.5
12-COARSE SAND	Percent less than sieve size 850	GRAIN	%	2.4	2.9	9.6	5.8	7.5
13-COARSE SAND	Percent less than sieve size 2000	GRAIN	%	1.5	1.7	6.3	5.1	5.2
Sum				100	100	100	100	100

Horseshoe Road, Sayreville, New Jersey
Sediment Samples
Grain Size Distribution

Cas Rn	Chemical Name	Analytic Method	Sample Code / Sample Date / Sample Matrix / Unit \\ Parent	SD16 10/27/97 Sediment	SD17 10/27/97 Sediment	SD18 10/29/97 Sediment	SD19 10/24/97 Sediment	SD20 10/24/97 Sediment
(Group Code)	**(Group Description)**							
Grain	**Grain Size Distribution**							
01-CLAY	Percent less than sieve size 1.25 - 1.47	HYDRO	%	6.9	11.1	28.8	19.6	0.6
02-CLAY	Percent less than sieve size 3 - 3.57	HYDRO	%	0.6	0.7	1.5	2.1	0.1
03-SILT	Percent less than sieve size 5.89 - 7.13	HYDRO	%	1.1	1.4	4.4	3	0
04-SILT	Percent less than sieve size 8.06 - 10.02	HYDRO	%	1.2	0.7	7.4	1	0
05-SILT	Percent less than sieve size 10.95 - 14.13	HYDRO	%	1.2	0.7	8.8	1	0.1
06-SILT	Percent less than sieve size 17.94 - 24.47	HYDRO	%	1.2	1.5	5.9	1	0
07-SILT	Percent less than sieve size 26.65 - 38.55	HYDRO	%	0.6	2.8	1.5	2	0.1
08-SILT	Percent less than sieve size 75	GRAIN	%	17.4	16	17.1	24	5.1
09-FINE-SAND	Percent less than sieve size 150	GRAIN	%	5	5.3	1.6	18.8	4.1
10-FINE-SAND	Percent less than sieve size 250	GRAIN	%	8.8	8	6.1	21.5	11.1
11-MEDIUM SAND	Percent less than sieve size 425	GRAIN	%	19.8	16.1	5.5	2.7	30.5
12-COARSE SAND	Percent less than sieve size 850	GRAIN	%	21.9	24.2	7.1	1.8	38.1
13-COARSE SAND	Percent less than sieve size 2000	GRAIN	%	14.3	11.5	4.3	1.5	10.2
Sum				100	100	100	100	100

Horseshoe Road, Sayreville, New Jersey
Sediment Samples
Grain Size Distribution

Cas Rn	Chemical Name	Analytic Method	Sample Code / Sample Date / Sample Matrix / Unit \\ Parent	SD21 10/24/97 Sediment	SD22 10/24/97 Sediment	SD23 10/24/97 Sediment	SD24 10/27/97 Sediment	SD25 10/29/97 Sediment
(Group Code)	**(Group Description)**							
Grain	**Grain Size Distribution**							
01-CLAY	Percent less than sieve size 1.25 - 1.47	HYDRO	%	1.5	12.2	13.2	23.1	26.8
02-CLAY	Percent less than sieve size 3 - 3.57	HYDRO	%	0.2	1.8	1.7	2.6	2.7
03-SILT	Percent less than sieve size 5.89 - 7.13	HYDRO	%	0 1	2.7	0.9	4	4.1
04-SILT	Percent less than sieve size 8.06 - 10 02	HYDRO	%	0.1	0.9	1.7	2.6	4.2
05-SILT	Percent less than sieve size 10.95 - 14 13	HYDRO	%	0 3	0.9	0.8	2.7	2.7
06-SILT	Percent less than sieve size 17 94 - 24.47	HYDRO	%	0.1	1.8	0.9	1.3	2.8
07-SILT	Percent less than sieve size 26 65 - 38.55	HYDRO	%	0 1	2.7	0.8	2.6	1.3
08-SILT	Percent less than sieve size 75	GRAIN	%	8	20.2	20.3	16.7	23.6
09-FINE-SAND	Percent less than sieve size 150	GRAIN	%	2.3	16.5	27.8	12.3	9
10-FINE-SAND	Percent less than sieve size 250	GRAIN	%	4.4	13.1	14.7	10.7	9.7
11-MEDIUM SAND	Percent less than sieve size 425	GRAIN	%	23.7	10.8	3.9	7.2	5.2
12-COARSE SAND	Percent less than sieve size 850	GRAIN	%	49.7	9.9	6	7.1	4.4
13-COARSE SAND	Percent less than sieve size 2000	GRAIN	%	9.5	6.5	7.3	7.1	3.5
Sum				100	100	100	100	100

Horseshoe Road, Sayreville, New Jersey
Sediment Samples
Grain Size Distribution

Cas Rn	Chemical Name	Analytic Method	Unit \\ Parent	SD26	SD27	SD28	SD29	SD30
			Sample Date	10/29/97	10/30/97	10/28/97	10/27/97	10/29/97
			Sample Matrix	Sediment	Sediment	Sediment	Sediment	Sediment
(Group Code)	**(Group Description)**							
Grain	**Grain Size Distribution**							
01-CLAY	Percent less than sieve size 1.25 - 1.47	HYDRO	%	28.2	24.5	44.4	39	27.5
02-CLAY	Percent less than sieve size 3 - 3.57	HYDRO	%	4.5	3.6	4	5.2	2.8
03-SILT	Percent less than sieve size 5.89 - 7 13	HYDRO	%	4.5	3.7	9.9	5.2	5.7
04-SILT	Percent less than sieve size 8.06 - 10.02	HYDRO	%	4.5	1.8	7.9	3.5	2.8
05-SILT	Percent less than sieve size 10.95 - 14 13	HYDRO	%	2.3	0	5.9	5.2	4.3
06-SILT	Percent less than sieve size 17 94 - 24 47	HYDRO	%	4.5	3.6	2	5.2	2.8
07-SILT	Percent less than sieve size 26.65 - 38.55	HYDRO	%	2.2	1.8	3.9	3.4	1.4
08-SILT	Percent less than sieve size 75	GRAIN	%	26.8	42	11.8	21.9	18 3
09-FINE-SAND	Percent less than sieve size 150	GRAIN	%	3 4	4.5	3.7	8.2	6 8
10-FINE-SAND	Percent less than sieve size 250	GRAIN	%	4.2	3.4	2.7	1.1	10.9
11-MEDIUM SAND	Percent less than sieve size 425	GRAIN	%	4.6	3.9	1.6	0.8	7.3
12-COARSE SAND	Percent less than sieve size 850	GRAIN	%	5.6	3.9	1.3	0.6	5.7
13-COARSE SAND	Percent less than sieve size 2000	GRAIN	%	4.7	3.3	0.9	0.7	3.7
Sum				100	100	100	100	100

Horseshoe Road, Sayreville, New Jersey
Sediment Samples
Grain Size Distribution

Cas Rn	Chemical Name	Analytic Method	Sample Code / Sample Date / Sample Matrix / Unit \\ Parent	SD31	SD32	SD33	SD34	SD35
			Sample Date	10/30/97	10/28/97	10/28/97	10/30/97	10/30/97
			Sample Matrix	Sediment	Sediment	Sediment	Sediment	Sediment
(Group Code)	**(Group Description)**							
Grain	**Grain Size Distribution**							
01-CLAY	Percent less than sieve size 1.25 - 1.47	HYDRO	%	44.7	47	39.8	34.5	39.2
02-CLAY	Percent less than sieve size 3 - 3.57	HYDRO	%	4.6	4.3	9.3	2.7	2
03-SILT	Percent less than sieve size 5.89 - 7.13	HYDRO	%	6.8	2.2	3.7	5.6	4.1
04-SILT	Percent less than sieve size 8.06 - 10.02	HYDRO	%	4.6	8.8	7.4	5.5	8
05-SILT	Percent less than sieve size 10.95 - 14.13	HYDRO	%	4.6	4.3	5.6	5.5	2
06-SILT	Percent less than sieve size 17.94 - 24.47	HYDRO	%	4.6	2.2	1.8	2.8	6.1
07-SILT	Percent less than sieve size 26.65 - 38.55	HYDRO	%	4.6	4.4	3.7	5.5	2
08-SILT	Percent less than sieve size 75	GRAIN	%	17.8	17	16.7	16.6	25.2
09-FINE-SAND	Percent less than sieve size 150	GRAIN	%	1.5	3.3	3.3	4.7	2.2
10-FINE-SAND	Percent less than sieve size 250	GRAIN	%	2.1	2.5	2.7	4.8	2.3
11-MEDIUM SAND	Percent less than sieve size 425	GRAIN	%	1.6	2.2	2.4	5	2.4
12-COARSE SAND	Percent less than sieve size 850	GRAIN	%	1.6	1.6	2.1	4.1	2.8
13-COARSE SAND	Percent less than sieve size 2000	GRAIN	%	0.9	0.2	1.5	2.7	1.7
Sum				100	100	100	100	100

Horseshoe Road, Sayreville, New Jersey
Sediment Samples
Grain Size Distribution

Cas Rn	Chemical Name	Analytic Method	Sample Code / Sample Date / Sample Matrix / Unit \\ Parent	SD36 10/30/97 Sediment	SD37 10/30/97 Sediment	SD40 10/24/97 Sediment SD20	SD41 10/30/97 Sediment SD37
(Group Code)	(Group Description)						
Grain	**Grain Size Distribution**						
01-CLAY	Percent less than sieve size 1.25 - 1 47	HYDRO	%	14.6	9.6	0.7	5.8
02-CLAY	Percent less than sieve size 3 - 3.57	HYDRO	%	1.8	0	0	0
03-SILT	Percent less than sieve size 5.89 - 7.13	HYDRO	%	2.7	0.8	0	0.5
04-SILT	Percent less than sieve size 8.06 - 10.02	HYDRO	%	1.7	0	0.1	0
05-SILT	Percent less than sieve size 10.95 - 14.13	HYDRO	%	1.8	0	0	0.4
06-SILT	Percent less than sieve size 17.94 - 24.47	HYDRO	%	2.7	0.7	0	0.4
07-SILT	Percent less than sieve size 26.65 - 38.55	HYDRO	%	0.9	1.4	0.1	0.5
08-SILT	Percent less than sieve size 75	GRAIN	%	15.7	20.7	5.4	15.3
09-FINE-SAND	Percent less than sieve size 150	GRAIN	%	9.9	8.1	4	21.1
10-FINE-SAND	Percent less than sieve size 250	GRAIN	%	19.1	19.2	10.7	18.4
11-MEDIUM SAND	Percent less than sieve size 425	GRAIN	%	11.5	17	33.7	15.6
12-COARSE SAND	Percent less than sieve size 850	GRAIN	%	9.9	14.8	35.1	14.1
13-COARSE SAND	Percent less than sieve size 2000	GRAIN	%	7.7	7.7	10.2	7.9
Sum				100	100	100	100

Horseshoe Road, Sayreville, New Jersey
Surface Samples
Grain Size Distribution

Cas Rn	Chemical Name	Analytic Method	Sample Code / Sample Date / Sample Matrix / Unit \\ Parent	SS01 10/20/97 Soil	SS02 10/20/97 Soil	SS03 10/20/97 Soil	SS20 10/20/97 Soil SS03	SS04 10/20/97 Soil
(Group Code)	**(Group Description)**							
Grain	**Grain Size Distribution**							
01-CLAY	Percent retained by sieve size 1.25 - 1.47	Hydro	%	3.1	7.8	5.4	3.8	1.3
02-CLAY	Percent retained by sieve size 3 - 3.57	Hydro	%	0.2	0.6	0.3	0.3	0.3
03-SILT	Percent retained by sieve size 5.89 - 7.13	Hydro	%	0.3	2.5	0.4	0.2	0.1
04-SILT	Percent retained by sieve size 8.06 - 10.02	Hydro	%	0.3	1.3	0.4	0.3	0.1
05-SILT	Percent retained by sieve size 10.95 - 14.13	Hydro	%	0.3	1.9	0.8	0	0.1
06-SILT	Percent retained by seive size 17.94 - 24.47	Hydro	%	0	1.2	0.8	0.3	0.1
07-SILT	Percent retained by sieve size 26.65 - 38.55	Hydro	%	8.3	15.8	11.5	6.8	6.9
08-SILT	Percent retained by sieve size 75	Grain	%	7.5	4.1	5.1	6.5	3.7
09-FINE-SAND	Percent retained by sieve size 150	Grain	%	25.2	11.2	8.3	8.9	5.9
10-FINE-SAND	Percent retained by sieve size 250	Grain	%	33.1	15.7	16.4	17.9	22.2
11-MEDIUM SAND	Percent retained by sieve size 425	Grain	%	17.3	17.6	25.1	27.8	45.2
12-COARSE SAND	Percent retained by sieve size 850	Grain	%	4.4	20.3	25.5	27.2	14.1
13-COARSE SAND	Percent retained by sieve size 2000	Grain	%	0	0	0	0	0
Sum				100	100	100	100	100

Horseshoe Road, Sayreville, New Jersey
Surface Samples
Grain Size Distribution

			Sample Code	SS06	SS08	SS09	SS10
			Sample Date	10/20/97	10/20/97	10/21/97	10/21/97
			Sample Matrix	Soil	Soil	Soil	Soil
Cas Rn	Chemical Name	Analytic Method	Unit \\ Parent				
(Group Code)	**(Group Description)**						
Grain	**Grain Size Distribution**						
01-CLAY	Percent retained by sieve size 1.25 - 1.47	Hydro	%	26.5	7.4	1.1	8.2
02-CLAY	Percent retained by sieve size 3 - 3.57	Hydro	%	6.4	1.6	0	1.1
03-SILT	Percent retained by sieve size 5.89 - 7.13	Hydro	%	2.6	0.6	0	0.6
04-SILT	Percent retained by sieve size 8.06 - 10.02	Hydro	%	3.9	0.5	0.1	0.5
05-SILT	Percent retained by sieve size 10.95 - 14.13	Hydro	%	2.5	0.6	0	0.6
06-SILT	Percent retained by seive size 17.94 - 24.47	Hydro	%	2.6	0.5	0.1	0.6
07-SILT	Percent retained by sieve size 26.65 - 38.55	Hydro	%	13.5	13.8	6.3	16.1
08-SILT	Percent retained by sieve size 75	Grain	%	9.9	6.2	3.8	9.9
09-FINE-SAND	Percent retained by sieve size 150	Grain	%	11	9.2	11.2	12.5
10-FINE-SAND	Percent retained by sieve size 250	Grain	%	8.3	17.9	29.8	18.1
11-MEDIUM SAND	Percent retained by sieve size 425	Grain	%	7	30.6	34.3	21
12-COARSE SAND	Percent retained by sieve size 850	Grain	%	5.8	11.1	13.3	10.8
13-COARSE SAND	Percent retained by sieve size 2000	Grain	%	0	0	0	0
Sum				100	100	100	100

Attachment C-2

Grain Size Results for Sediment Samples

Exponent Grain (particle) size results for sediment samples.

X coordinate	Y coordinate	Projection	Survey	Survey station	Percent clay (D422M NONE) (% dry)	Percent silt (D422M NONE) (% dry)	Phi class 3.00+ to 4.00 (D422M NONE) (% dry)	Phi class 2.00+ to 3.00 (D422M NONE) (% dry)	Phi class 1.00+ to 2.00 (D422M NONE) (% dry)	Phi class 0.00+ to 1.00 (D422M NONE) (% dry)	Phi class -1.00+ to 0.00 (D422M NONE) (% dry)	Phi class -2.00+ to -1.00 (D422M NONE) (% dry)	Phi class -3.00+ to -2.00 (D422M NONE) (% dry)
541457.313	602425.067	NAD83	HRSESHOE	1	4.1	8.4	0.85	9.3	12	26	9.9	4.7	21
542103.8884	603037.4435	NAD83	HRSESHOE	10	21	35	4.7	26	6.4	3.2	2.8	0.78	0
542036.7597	602197.4602	NAD83	HRSESHOE	11A	21	33	4.7	13	5.8	7.2	5.0	4.2	2.8
541844.1298	602435.0372	NAD83	HRSESHOE	12	17	53	0.89	2.8	2.4	3.2	5.9	7.2	7.2
541949.2245	602526.394	NAD83	HRSESHOE	13	26	43	3.8	9.1	5.6	6.4	4.8	2.0	0
541701.7004	602255.2492	NAD83	HRSESHOE	13A	2.3	6.8	2.4	26	27	25	7.4	2.3	2.0
541893.0129	602735.9759	NAD83	HRSESHOE	14	21	29	1.1	4.2	4.2	7.1	13	15	3.5
541896.6652	602322.9616	NAD83	HRSESHOE	16	22	61	2.3	3.7	2.1	2.5	3.3	1.4	0
541969.0474	602394.1763	NAD83	HRSESHOE	17	13	30	3.6	13	13	14	11	2.9	0.58
541969.0474	602394.1763	NAD83	HRSESHOE	17	16	32	3.9	14	12	11	8.5	4.4	1.1
542208.3755	602554.1175	NAD83	HRSESHOE	18A	6.2	29	7.4	22	9.0	9.2	10	5.8	0.71
542055.439	602606.0692	NAD83	HRSESHOE	19	35	35	0.56	2.3	2.1	3.8	6.5	8.9	4.8
541503.367	602463.715	NAD83	HRSESHOE	2	14	38	1.6	14	14	9.3	4.0	1.4	3.4
542068.8647	602328.7988	NAD83	HRSESHOE	22	20	37	3.1	8.9	4.2	4.2	4.8	5.5	16
541642.744	602448.4629	NAD83	HRSESHOE	3	12	57	2.4	12	5.0	4.4	4.2	1.4	0
541663.1744	602588.5574	NAD83	HRSESHOE	4	21	65	1.8	5.5	3.2	2.6	2.9	0.70	0
541725.954	602658.217	NAD83	HRSESHOE	5	21	48	2.3	5.8	5.1	3.8	4.2	2.9	8.1
541849.161	602792.098	NAD83	HRSESHOE	6	5.1	32	1.9	15	13	9.8	8.6	7.2	7.5
542120.758	602944.209	NAD83	HRSESHOE	7R	3.6	7.1	2.1	32	20	11	8.5	7.6	8.5
542003.4873	602766.5942	NAD83	HRSESHOE	8	13	44	6.0	16	4.6	4.0	4.0 *J*	1.9	3.7 *J*
542003.4873	602766.5942	NAD83	HRSESHOE	8	16	49	5.8	15	4.6	3.4	2.3 *J*	1.7	1.8 *J*
542181.744	602774.407	NAD83	HRSESHOE	9	48	36	3.6	6.5	0.89	0.66	1.0	0.90	0.54 *J*
541201.894	602133.757	NAD83	HRSESHOE	AQUAREF1	25	29	1.7	20	14	7.5	3.0	0.91	0
540924.09	601863.866	NAD83	HRSESHOE	AQUAREF2	18	70	1.2	2.4	1.2	1.2	1.9	3.0	0.93
540597.1634	601603.7393	NAD83	HRSESHOE	AQUAREF3	27	52	0.45	2.0	1.8	2.9	5.4	4.9	2.3
542449.58	603553.494	NAD83	HRSESHOE	AQUAREF4	9.8	17	2.7	26	18	7.5	3.1	3.1	13
542719.774	603967.738	NAD83	HRSESHOE	AQUAREF5	2.1	3.1	0.48	9.3	28	17	4.6	5.9	29
541375.383	602215.015	NAD83	HRSESHOE	TERRREF1	10	32	3.2	13	11	17	9.6	1.6	0.54
541425.973	602123.239	NAD83	HRSESHOE	TERRREF2	14	29	4.9	26	15	7.5	3.5	1.8	0
541394.739	602090.81	NAD83	HRSESHOE	TERRREF3	16	34	3.0	15	9.6	11	11	2.4	0.86

Attachment C-3

Excerpt from NOAA Atlas 14

POINT PRECIPITATION FREQUENCY ESTIMATES FROM NOAA ATLAS 14

NEW JERSEY 40.49 N 74.32 W 39 feet

from "Precipitation-Frequency Atlas of the United States" NOAA Atlas 14, Volume 2, Version 3
G.M. Bonnin, D. Martin, B. Lin, T. Parzybok, M.Yekta, and D. Riley
NOAA, National Weather Service, Silver Spring, Maryland, 2004
Extracted: Wed Feb 6 2008

Precipitation Frequency Estimates (inches)

AEP* (1-in-Y)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
2	0.37	0.59	0.74	1.02	1.28	1.57	1.75	2.23	2.72	3.09	3.61	4.03	4.69	5.31	7.10	8.81	11.16	13.32
5	0.46	0.74	0.94	1.33	1.71	2.12	2.35	3.00	3.68	4.22	4.90	5.43	6.20	6.91	9.01	10.95	13.68	16.17
10	0.52	0.83	1.06	1.53	1.99	2.50	2.78	3.56	4.40	5.09	5.88	6.46	7.30	8.06	10.29	12.33	15.27	17.90
25	0.59	0.94	1.19	1.77	2.35	3.01	3.35	4.34	5.43	6.36	7.27	7.90	8.81	9.62	11.95	14.03	17.18	19.94
50	0.64	1.01	1.28	1.94	2.62	3.41	3.80	4.96	6.30	7.43	8.43	9.07	10.04	10.85	13.20	15.27	18.54	21.35
100	0.68	1.09	1.37	2.10	2.90	3.82	4.27	5.64	7.24	8.63	9.70	10.33	11.36	12.16	14.46	16.47	19.85	22.66
200	0.73	1.15	1.45	2.26	3.17	4.25	4.77	6.36	8.29	9.97	11.10	11.70	12.76	13.54	15.74	17.66	21.11	23.89
500	0.78	1.23	1.55	2.47	3.54	4.85	5.45	7.41	9.84	12.00	13.17	13.68	14.77	15.50	17.46	19.18	22.70	25.39
1000	0.82	1.29	1.62	2.62	3.82	5.34	6.00	8.27	11.17	13.75	14.92	15.32	16.43	17.08	18.78	20.31	23.85	26.44

Text version of table

* These precipitation frequency estimates are based on an annual maxima series. AEP is the Annual Exceedance Probability.
Please refer to the documentation for more information. NOTE: Formatting forces estimates near zero to appear as zero.

*** Upper bound of the 90% confidence interval**
Precipitation Frequency Estimates (inches)

AEP** (1-in-Y)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
2	0.41	0.65	0.82	1.13	1.41	1.74	1.94	2.48	3.04	3.42	4.00	4.43	5.10	5.74	7.58	9.32	11.74	13.97
5	0.51	0.82	1.03	1.47	1.88	2.35	2.61	3.33	4.10	4.66	5.43	5.97	6.75	7.47	9.60	11.57	14.40	16.95
10	0.58	0.92	1.17	1.69	2.20	2.77	3.08	3.94	4.89	5.61	6.50	7.10	7.95	8.71	10.97	13.03	16.06	18.77
25	0.65	1.04	1.31	1.95	2.59	3.32	3.71	4.79	6.02	6.98	8.04	8.67	9.59	10.40	12.74	14.83	18.08	20.92
50	0.70	1.12	1.41	2.13	2.89	3.76	4.21	5.47	6.97	8.15	9.31	9.96	10.93	11.73	14.09	16.16	19.53	22.41
100	0.75	1.20	1.51	2.32	3.19	4.22	4.72	6.21	8.01	9.47	10.73	11.35	12.38	13.18	15.46	17.45	20.93	23.80
200	0.80	1.27	1.60	2.49	3.50	4.70	5.27	7.01	9.17	10.96	12.30	12.88	13.93	14.71	16.86	18.74	22.29	25.13
500	0.86	1.36	1.72	2.73	3.92	5.39	6.05	8.18	10.90	13.22	14.64	15.11	16.22	16.92	18.78	20.44	24.06	26.79
1000	0.91	1.43	1.79	2.91	4.24	5.94	6.68	9.15	12.39	15.19	16.65	17.00	18.13	18.75	20.28	21.73	25.38	27.97

* The upper bound of the confidence interval at 90% confidence level is the value which 5% of the simulated quantile values for a given frequency are greater than.
** These precipitation frequency estimates are based on an annual maxima series. AEP is the Annual Exceedance Probability.
Please refer to the documentation for more information. NOTE: Formatting prevents estimates near zero to appear as zero.

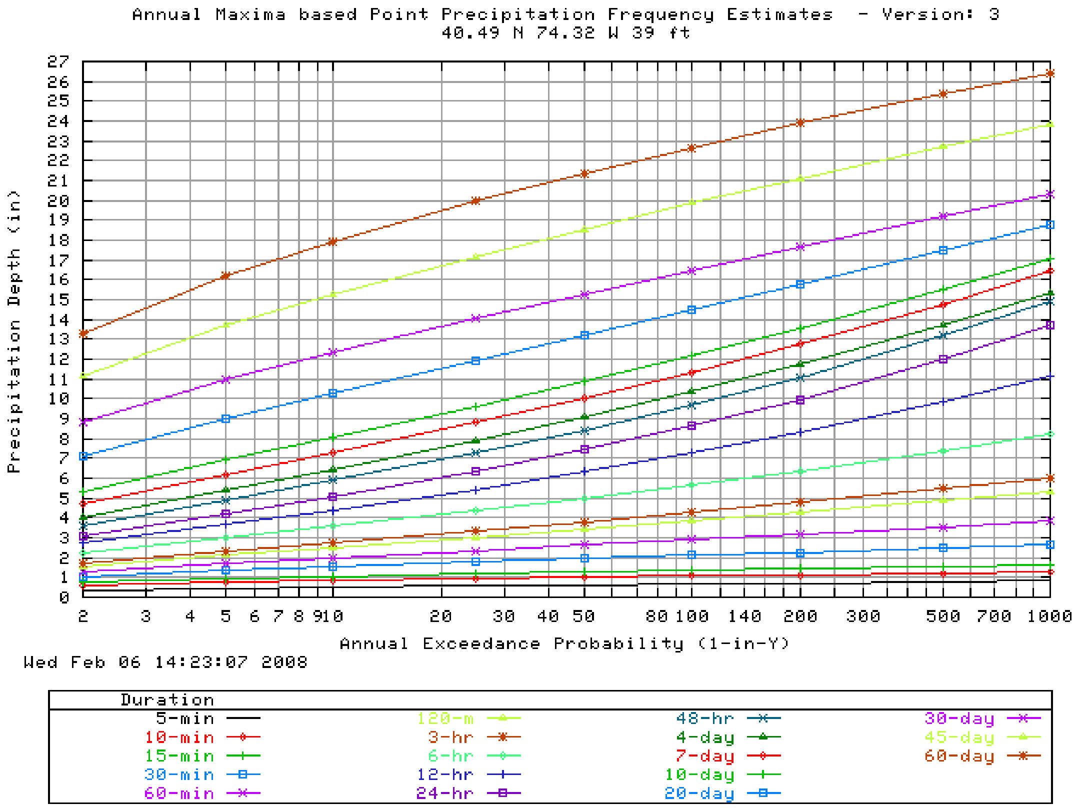
*** Lower bound of the 90% confidence interval**
Precipitation Frequency Estimates (inches)

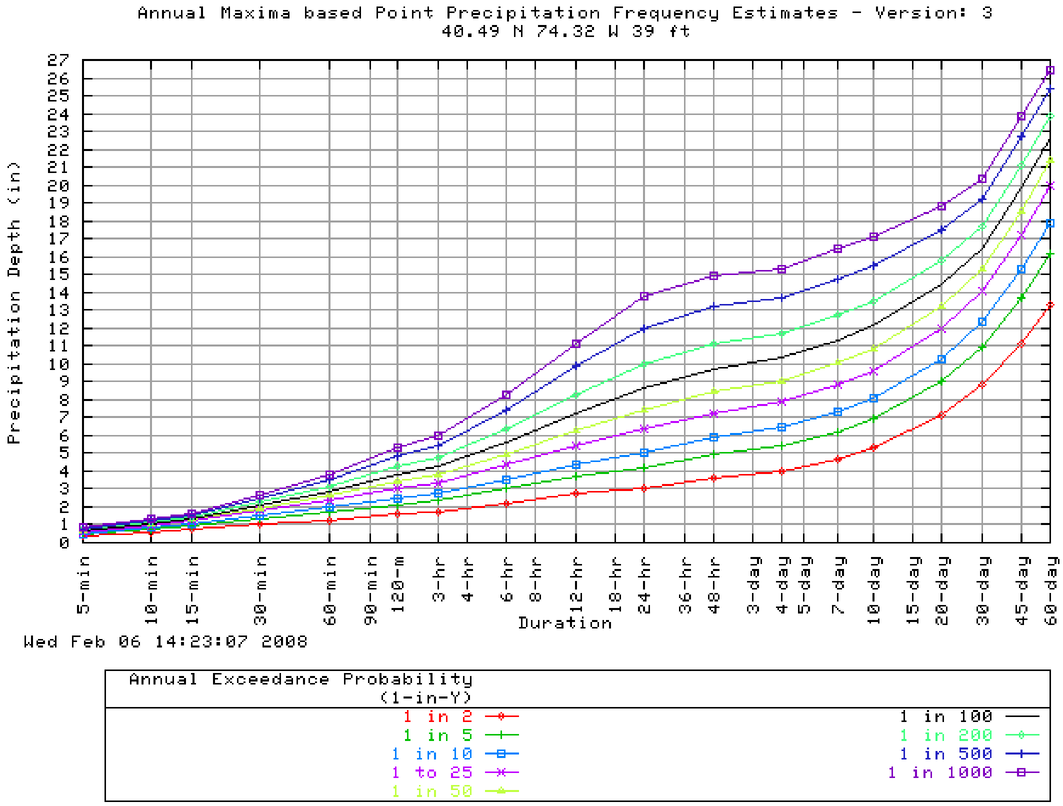
AEP** (1-in-Y)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
2	0.33	0.53	0.67	0.93	1.16	1.42	1.58	2.01	2.44	2.82	3.28	3.68	4.32	4.93	6.67	8.34	10.60	12.70
5	0.42	0.67	0.85	1.21	1.55	1.91	2.13	2.70	3.30	3.84	4.45	4.95	5.71	6.41	8.44	10.36	12.98	15.41
10	0.47	0.76	0.96	1.38	1.80	2.25	2.51	3.19	3.93	4.61	5.31	5.87	6.71	7.45	9.64	11.65	14.47	17.05
25	0.53	0.85	1.07	1.59	2.12	2.69	3.00	3.85	4.81	5.73	6.53	7.15	8.05	8.85	11.14	13.22	16.25	18.95
50	0.57	0.91	1.15	1.73	2.35	3.03	3.39	4.38	5.54	6.64	7.53	8.16	9.11	9.93	12.27	14.34	17.49	20.25
100	0.61	0.97	1.22	1.87	2.58	3.37	3.78	4.92	6.29	7.65	8.59	9.22	10.23	11.05	13.37	15.42	18.67	21.44
200	0.64	1.02	1.28	2.00	2.81	3.73	4.18	5.50	7.11	8.73	9.72	10.35	11.40	12.21	14.47	16.46	19.79	22.54

500	0.68	1.08	1.36	2.16	3.10	4.21	4.72	6.31	8.29	10.34	11.35	11.94	13.01	13.80	15.90	17.77	21.16	23.84
1000	0.71	1.12	1.41	2.28	3.32	4.58	5.14	6.97	9.26	11.66	12.67	13.20	14.31	15.05	16.98	18.70	22.12	24.75

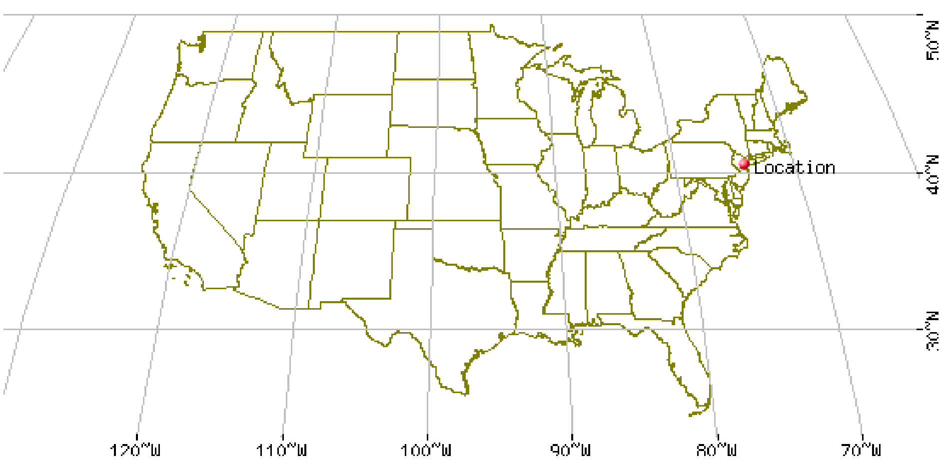
* The lower bound of the confidence interval at 90% confidence level is the value which 5% of the simulated quantile values for a given frequency are less than.
** These precipitation frequency estimates are based on an annual maxima series. AEP is the Annual Exceedance Probability.

Please refer to the documentation for more information. NOTE: Formatting prevents estimates near zero to appear as zero.



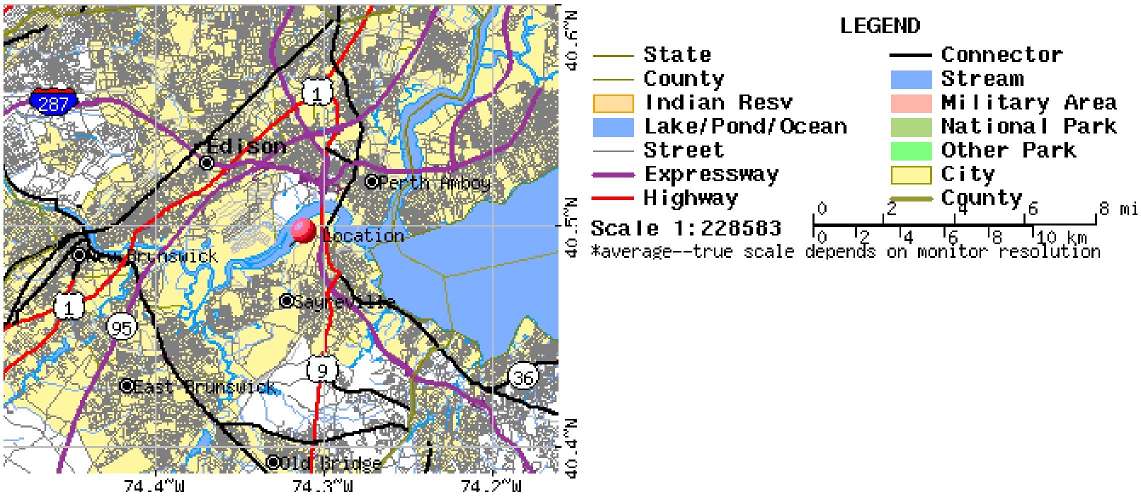


Maps -



These maps were produced using a direct map request from the U.S. Census Bureau Mapping and Cartographic Resources Tiger Map Server.

Please read disclaimer for more information.



Other Maps/Photographs -

View USGS digital orthophoto quadrangle (DOQ) covering this location from TerraServer; **USGS Aerial Photograph** may also be available from this site. A DOQ is a computer-generated image of an aerial photograph in which image displacement caused by terrain relief and camera tilts has been removed. It combines the image characteristics of a photograph with the geometric qualities of a map. Visit the USGS for more information.

Watershed/Stream Flow Information -

Find the Watershed for this location using the U.S. Environmental Protection Agency's site.

Climate Data Sources -

Precipitation frequency results are based on data from a variety of sources, but largely NCDC. The following links provide general information about observing sites in the area, regardless of if their data was used in this study. For detailed information about the stations used in this study, please refer to our documentation.

Using the **National Climatic Data Center's (NCDC)** station search engine, locate other climate stations within:

+/-30 minutes ...OR... +/-1 degree of this location (40.49/-74.32). Digital ASCII data can be obtained directly from **NCDC**.

Hydrometeorological Design Studies Center
DOC/NOAA/National Weather Service
1325 East-West Highway
Silver Spring, MD 20910

(301) 713-1669
Questions?: HDSC.Questions@noaa.gov

Appendix D

Geochemical Modeling

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Simulated Arsenic Transport and Fate through Uncontaminated Cover Materials (HP1 Modeling)

Introduction

This technical memorandum describes a geochemical transport model that was used to evaluate the potential for recontamination of clean cover materials placed over residual contaminated sediments at OU-3 of the Horseshoe Road/ARC Superfund sites near Sayreville, New Jersey. As evidenced by the spatial distribution of arsenic in surface samples (concentrations generally increase with proximity to the SPD/ADC drainages), sediment dispersion from the facilities' drainage creeks was historically the principal source of arsenic to the marsh. Under a partial removal scenario, this potential recontamination mechanism is not operative. Instead, the primary mechanism potentially leading to cover recontamination is the release of arsenic from unremoved soil buried at depth, followed by upward (or lateral) migration and repartitioning onto cover material.

Cover recontamination via diffusive transport largely depends on the following factors: 1) the rate of dissolution of arsenic from the minerals below the cover; 2) the diffusive flux of arsenic-containing porewater into the cover; and 3) the extent of sequestration of dissolved arsenic by cover minerals. The potential for recontamination is expected to be higher for the following conditions: the affinity for arsenic from soil materials below the cover is low; there is greater hydrologic connectivity between the cover and unremoved soil; and the cover has a high affinity (i.e., sorptive capacity) for arsenic.

The first of factor affecting cover recontamination, the rate of dissolution of arsenic into porewater, largely[1] depends on the types of minerals present. This is because soil arsenic is distributed between a number of chemical forms, each exhibiting a different affinity for arsenic, and hence a different potential, to be released. The predominant chemical forms likely occurring in OU-3 include the following: 1) arsenic adsorbed onto the surfaces of clays, iron oxides, and iron sulfide minerals; 2) arsenic residing within the crystalline structure of iron-bearing phases; and 3) arsenic sulfides such as realgar or orpiment.[2] Near the soil surface, iron-III oxide minerals (such as ferrihydrite) will be the predominant host for arsenic (Cances et al. 2005). By contrast, near (and below) the groundwater table, arsenic will exhibit a greater propensity to be retained in and/or on iron sulfides (Bostick and Fendorf 2003).[3] Because sulfides generally adsorb less arsenic than ferrihydrite, dissolved concentrations can be higher

[1] Aqueous chemistry (e.g., pH, redox potential, competing anions).

[2] Organic matter can also host arsenic, although the exact mechanism responsible for this association is a subject of current research.

[3] This is, in turn, directly linked to biological activity within the marsh, because biodegradation of soil organic matter generates reducing conditions, which favors the dissolution of iron-III oxides and the precipitation of sulfides.

below the groundwater table. Whether or not this occurs depends on the extent that arsenic is retained within (and thereby removed from the surface of) precipitating iron sulfide minerals. If dissolved concentrations are high enough, arsenic sulfide minerals, such as orpiment or realgar, can precipitate at depth (O'Day et al. 2004).

The second factor influencing recontamination, the diffusive flux of the arsenic dissolved from soil minerals, will be affected by the connectivity of pore spaces in the marsh, as well as the degree of saturation of the cover and soil. In OU-3, the hydrologic link between the cover and the unremoved soil will vary as a function of time resulting from precipitation, evapotranspiration, and tidal fluctuations. It would be expected that the link between the cover and underlying soil will be established over longer time periods in the lower marsh (where daily tidal transgressions keep the water table closer to the surface), and that this would necessarily (all other factors being equal) make the potential for recontamination greater in the lower marsh.

Finally, the hydrologic and geochemical properties of the cover will affect the potential for recontamination. To the extent that the cover is above the groundwater table, iron-III oxides will be present. These have a relatively high potential to retain arsenic.[4]

Numerical Model

In order to predict cover recontamination it is necessary to model the following processes: tidal-varying groundwater conditions; saturated and vadose zone transport; and arsenic solubility with respect to the various mineral phases described above. The model selected for this study was HP1 (Jacques and Simunek 2005), which combines the unsaturated zone transport of HYDRUS 1-D (Simunek et al. 1998) with the geochemical processes of the USGS-supported model PHREEQC (Parkhurst and Appelo 1999).

1-D reactive transport modeling was performed on a 1-m long soil columns,[5] representing the marsh. Upper hydrologic boundary conditions on the columns were prescribed as a variable head, and were dependent on tidal elevation, precipitation, and evapotranspiration. Atmospheric (and tidal) data used for these conditions were based on the following 2005 atmospheric and tidal data: 1) hourly tidal elevations for Sayreville (Surgent 2007); hourly precipitation for Newark (NOAA 2005); and monthly average evapotranspiration rates, expressed on an hourly basis (M^2 Associates 2003). Lower boundary conditions were specified as constant head, based on the position of the soil columns relative to the mean tidal water level (Ursino et al. 2004). The soil hydrological properties were set to default values available in the HYDRUS 1-D model for a loam (which is the classification provided by grain-size analysis in OU-3). Finally, the effective diffusion constant for arsenic was set to a value representative of the combined processes of bioturbation and root growth in the marsh (Fischer and Reddy 2001).

The HP1 model was run in two steps. The first step consisted of a 1-D reactive transport simulation. Initial and boundary conditions included the flow conditions specified above, the

[4] Because of this, however, dissolved arsenic concentrations may be low.

[5] The selection of 1-D transport conditions is generally consistent with flow in areas away from tidal creeks or other groundwater discharge areas (Ursino et al. 2004).

elements Na-Cl-H-O-Fe-S-As, sediment concentrations from other marsh systems (Weiss et al. 2004), river and rainfall concentrations of elements from the USGS (2007) and Conko et al. (2004), respectively, and biogeochemical reactions developed by Hunter et al. (1998), using an

organic matter decomposition rate determined in New Jersey marshes (Windham 2001). This initial model was run for a period of 6 months to determine the distribution of iron oxide and sulfide minerals in the upper marsh sediment profile.[6] Because no data were available to calibrate the model, the results could only be compared to other systems. Iron and sulfate reduction rates were found to be consistent with previous studies (Weiss et al. 2004; Gribsholt and Kristense 2002). Also, the distribution of arsenic in the marsh was consistent with O'Day et al. (2004) and Keimowitz et al. (2005).

The second series of HP1 runs, which were used to make predictions, directly transported arsenic (III and V) in the column, assuming an initial concentration of 400 mg/kg above 6 in. and 200 mg/kg between 6 and 18 in., and 100 mg/kg below 6 in. (similar to sample SDM-08). The distribution of iron oxide, iron sulfide, and clay minerals was assumed to be invariant (i.e., the number of sorptive surface sites available for arsenic adsorption were fixed based on the results of the initial step described above). By contrast, the total abundance of realgar (AsS) was varied (allowing it to freely dissolve over time). Each simulation was initially run for 1 year assuming no cover (in order to initialize dissolved concentrations). One of two possible covers was then included and modeled for a period of 4 years. Cover 1 was assumed to be 30-cm thick and consist of clean fill. Cover 2 was assumed to be 15-cm thick and consist of clay. Sorptive surfaces in the cover included iron-II and -III oxides, and clay. Differences in the hydrological properties of the clay relative to loam were not included in the model.

Results

Tables D-1a and D-1b show time varying soil arsenic concentrations in the marsh for the two covers for the 4-year simulation period. For each scenario, concentrations are predicted to be highest at the base of the cover. There is a general increase in arsenic concentrations initially, followed by a decline within 4 years (Tables D-1a and D-1b). This result is consistent with an overall decrease in the arsenic source over time. The model also predicts that arsenic concentrations will be higher in the clay cover. This result is partly the result of the fact that in the clay scenario, the base of the clay cover was modeled as containing higher concentrations of iron-III oxides directly adjacent to the unremoved soil (as discussed above, these minerals are very effective at sequestering dissolved arsenic[7]).

Dissolved concentrations generally mirror the sediment results, with the highest concentrations occurring at the base of the cover and an eventual decrease in concentration within the modeled 4-year time period (Tables D-2a and D-2b).

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6 The depth intervals over which each is stable.

7 For the clean fill, it was assumed for the iron-III oxides were not stable below the groundwater table, which occurs at approximately 16–17 cm bgs.

Discussion

There are two competing processes occurring in the cover with time. The first is the continual leaching of arsenic from the soil column. The second is the diffusion of arsenic and adsorption to oxides and clays in the cover. Initially, the chemical gradient between the cover and unremoved sediment causes a mass flux of arsenic into the cap. However, within the time frame of the model simulation, arsenic decreases in both the cover and unremoved sediment.

Uncertainty

The model only included 1-D processes and is therefore most applicable to areas where flux is predominantly vertical. The model also assumed equilibrium between arsenic-bearing minerals and dissolved phases. In fact, desorption and dissolution of arsenic into the porewater will be slower than modeled. This, in turn, will cause predicted changes to occur more rapidly than will actually likely occur in OU-3. It is believed that this modeling approach is conservative, because the modeled dissolved concentrations potentially diffusing into the cover will be higher as a result of the higher dissolved concentrations (i.e. there will be less dilution by infiltrating tides).

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Tables

Table D-1a. Total arsenic concentration in Cap 1 with time (mg/kg)

Depth (cm)	1 Year	2 Year	3 Year	4 Year
0	20.5	21.6	22.0	22.1
-1	20.6	21.7	22.2	22.2
-2	20.6	21.8	22.3	22.2
-3	20.7	22.0	22.4	22.3
-4	20.8	22.2	22.6	22.4
-5	21.0	22.4	22.8	22.6
-6	21.3	22.8	23.1	22.8
-7	21.7	23.2	23.4	23.1
-8	22.1	23.7	23.9	23.5
-9	22.7	24.4	24.4	24.0
-10	23.5	25.2	25.1	24.7
-11	24.6	26.3	26.2	25.8
-12	26.0	27.8	27.6	27.3
-13	28.1	30.0	29.9	29.6
-14	31.3	33.5	33.5	33.3
-15	36.8	39.4	39.4	38.9
-16	47.0	50.0	49.1	47.4
-17	13.9	11.4	9.8	8.8
-18	16.8	13.0	10.9	9.5
-19	19.6	14.7	12.0	10.3
-20	22.0	16.3	13.0	11.0
-21	24.2	17.8	14.1	11.8
-22	26.1	19.1	15.0	12.5
-23	27.8	20.3	15.9	13.2
-24	29.2	21.4	16.7	13.8
-25	30.4	22.2	17.4	14.4
-26	31.4	22.9	18.0	14.8
-27	32.1	23.4	18.4	15.2
-28	32.6	23.7	18.7	15.6
-29	32.8	23.9	18.9	15.8
-30	32.7	23.9	19.0	16.0
Average	**25.8**	**23.6**	**21.9**	**20.5**

Table D-1b. Total arsenic concentration in Cap 2 with time (mg/kg)

Depth (cm)	1 Year	2 Year	3 Year	4 Year
0	22.7	24.1	23.8	23.2
-1	23.0	24.5	24.2	23.6
-2	23.4	24.9	24.6	23.9
-3	23.9	25.4	25.0	24.2
-4	24.6	26.0	25.5	24.6
-5	25.4	26.7	26.1	25.2
-6	26.4	27.6	26.9	25.9
-7	27.7	28.7	27.9	26.9
-8	29.3	30.1	29.3	28.3
-9	31.5	32.1	31.3	30.5
-10	34.5	35.1	34.4	33.7
-11	38.9	39.6	39.1	38.7
-12	45.9	46.9	46.6	46.2
-13	58.0	59.1	58.6	57.5
-14	81.1	80.5	77.4	73.7
-15	133.5	120.4	106.8	95.6
Average	**40.6**	**40.7**	**39.2**	**37.6**

Table D-2a. Dissolved arsenic concentration in Cap 1 with time (mg/L)

Depth (cm)	1 Year	2 Year	3 Year	4 Year
0	0.002	0.004	0.005	0.005
-1	0.002	0.005	0.006	0.005
-2	0.002	0.005	0.006	0.006
-3	0.003	0.006	0.007	0.006
-4	0.003	0.006	0.007	0.007
-5	0.004	0.007	0.008	0.007
-6	0.004	0.008	0.009	0.008
-7	0.005	0.009	0.009	0.008
-8	0.006	0.010	0.010	0.009
-9	0.008	0.012	0.011	0.010
-10	0.009	0.013	0.012	0.010
-11	0.012	0.015	0.013	0.011
-12	0.014	0.017	0.015	0.012
-13	0.017	0.019	0.016	0.013
-14	0.021	0.021	0.017	0.014
-15	0.025	0.024	0.019	0.015
-16	0.030	0.027	0.021	0.016
-17	0.038	0.030	0.023	0.017
-18	0.046	0.034	0.025	0.019
-19	0.054	0.038	0.027	0.020
-20	0.062	0.042	0.029	0.021
-21	0.070	0.046	0.031	0.023
-22	0.079	0.050	0.034	0.024
-23	0.088	0.054	0.036	0.026
-24	0.098	0.059	0.039	0.027
-25	0.108	0.063	0.041	0.029
-26	0.118	0.068	0.044	0.030
-27	0.129	0.073	0.046	0.032
-28	0.140	0.078	0.049	0.033
-29	0.152	0.083	0.051	0.035
-30	0.164	0.088	0.054	0.036
Average	**0.049**	**0.033**	**0.023**	**0.017**

Table D-2b. Dissolved arsenic concentration in Cap 2 with time (mg/L)

Depth (cm)	1 Year	2 Year	3 Year	4 Year
0	0.009	0.012	0.011	0.009
-1	0.010	0.014	0.012	0.010
-2	0.011	0.015	0.013	0.011
-3	0.012	0.016	0.015	0.012
-4	0.014	0.018	0.016	0.013
-5	0.016	0.020	0.017	0.014
-6	0.019	0.022	0.019	0.015
-7	0.022	0.024	0.020	0.016
-8	0.025	0.026	0.022	0.017
-9	0.030	0.029	0.023	0.018
-10	0.034	0.031	0.025	0.020
-11	0.040	0.034	0.027	0.021
-12	0.046	0.038	0.029	0.023
-13	0.053	0.042	0.032	0.025
-14	0.061	0.046	0.035	0.027
-15	0.072	0.052	0.039	0.030
Average	**0.030**	**0.027**	**0.022**	**0.018**

Appendix E

Cost Estimates

Alternative M1—No Action

Capital Costs				
COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
		Total Direct Capital Costs:		$0
Indirect Capital Costs				
		Total Indirect Capital Costs:		$0
Total Capital Costs				**$0**
Operating Costs				
		Total Annual Costs:		$0
Periodic Costs				
Five Year Reviews	each	6	$50,000	$300,000
Net Present Value Analysis				
Project Duration (period)		30		
Discount Factor		7.0%		
NPV of Capital Costs				$0
NPV of Annual O&M Costs				$0
NPV of Periodic Costs				$107,891
Total Estimated Costs (NPV)				**$107,891**

Notes:

[A] *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* , EPA 540-R-00-002

Alternative M2—Channel Excavation, Thin Cover, and MNR

Capital Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Excavation Costs				
Clearing the Site	Acre	4.6	$1,217	$5,598
Load, Haul, and Disposal of Debris	CY	14,843	$24	$358,154
Excavate Contaminated Soil	CY	2,400	$47	$112,800
Load, Haul and Disposal of Non-Hazardous Materials to Landfill	CY	-	$105	$0
Load, Haul and Disposal at Subtitle C Landfill	CY	3,600	$220	$792,000
Sheet pile	SF	2,250	$18	$41,509
			Subtotal:	$1,310,061
Cover Costs				
Commercial Pelitized Clay Placement	CY	3,711	$300	$1,113,200
			Subtotal:	$1,113,200
Site Restoration				
Habitat Loss Mitigation	Acre	9.2	$100,000	$920,000
Obtain, Haul and Place Backfill	CY	2,400	$54	$129,600
Channel Armor Placement	LF	900	$100	$90,000
Perimeter Fencing	LF	3,000	$13	$38,250
Re-establish Marsh Vegetation	AC	0.30	$3,480	$1,044
			Subtotal:	$1,178,894
Mobilization/Demobilization	LS	1	$330,240	$330,240
Site preparation (15 feet wide approach road)	LF	2,800	$25	$70,000
15 feet wide berm construction	LF	100	$75	$7,500
Pre-design investigation	LS	1	$50,000	$50,000
			Subtotal	$457,740
		Total Direct Capital Costs:		$4,059,894
Indirect Capital Costs				
Engineering[A]	% of Direct Costs	20%		$811,979
Project Management[A]	% of Direct Costs	10%		$405,989
Construction Oversight[A]	% of Direct Costs	15%		$608,984
Scope & Bid Contingency (15% Each)[A]	% of Direct Costs	30%		$1,217,968
		Total Indirect Capital Costs:		$3,044,921
Total Capital Costs				**$7,104,815**

Operating Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Annual Direct Costs				
Site Maintenance	per Visit	4	$300	$1,200
		Total Annual Direct Costs:		$1,200
Annual Indirect Costs				
Project Management[A]	% of Direct Costs	5%	$1,200	$60
Technical Support[A]	% of Direct Costs	10%	$1,200	$120
Contingency[A]	% of Direct Costs	30%	$1,200	$360
		Total Annual Indirect Costs:		$540
		Total Annual Costs:		$1,740

Periodic Costs

Five Year Reviews	each	6	$50,000	$300,000
Annual monitoring for first 5 years	each	5	$50,000	$250,000
		Total Periodic Costs:		$550,000

Net Present Value Analysis

Project Duration (period)	30	
Discount Factor	7.0%	
NPV of Capital Costs		$7,104,815
NPV of Annual O&M Costs		$21,592
NPV of Periodic Costs		$312,901
Total Estimated Costs (NPV)		**$7,439,308**

Notes:

[A] *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* , EPA 540-R-00-002

Alternative M3—Surficial Hot Spot Removal and MNR

Capital Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Excavation Costs				
Clearing the Site	Acre	2.2	$1,217	$2,677
Load, Haul, and Disposal of Debris	CY	7,099	$24	$171,291
Excavate Contaminated Soil	CY	7,989	$47	$375,474
Load, Haul and Disposal of Non-Hazardous Materials to Landfill	CY	-	$105	$0
Load, Haul and Disposal at Subtitle C Landfill	CY	11,983	$220	$2,636,304
Sheet pile	SF	2,250	$18	$41,509
			Subtotal:	$3,227,255
Site Restoration				
Obtain, Haul and Place Backfill	CY	7,989	$54	$431,395
Perimeter Fence	LF	3,000	$13	$38,250
Re-establish Marsh Vegetation	AC	2.20	$3,480	$7,656
			Subtotal:	$477,301
Mobilization/Demobilization	LS	1	$553,341	$553,341
Site preparation (15 feet wide approach road)	LF	2,800	$25	$70,000
15 feet wide berm construction	LF	100	$75	$7,500
Pre-design investigation	LS	1	$50,000	$50,000
			Subtotal	$680,841
		Total Direct Capital Costs:		$4,385,397
Indirect Capital Costs				
Engineering[A]	% of Direct Costs	20%		$877,079
Project Management[A]	% of Direct Costs	10%		$438,540
Construction Oversight[A]	% of Direct Costs	15%		$657,810
Scope & Bid Contingency (15% Each)[A]	% of Direct Costs	30%		$1,315,619
		Total Indirect Capital Costs:		$3,289,048
Total Capital Costs				**$7,674,445**

Operating Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Annual Direct Costs				
Site Maintenance	per Visit	4	$300	$1,200
		Total Annual Direct Costs:		$1,200
Annual Indirect Costs				
Project Management[A]	% of Direct Costs	5%	$1,200	$60
Technical Support[A]	% of Direct Costs	10%	$1,200	$120
Contingency[A]	% of Direct Costs	30%	$1,200	$360
		Total Annual Indirect Costs:		$540
		Total Annual Costs:		$1,740

Periodic Costs

Five Year Reviews	each	6	$50,000	$300,000
Annual monitoring for first 5 years	each	5	$50,000	$250,000
		Total Periodic Costs:		$550,000

Net Present Value Analysis

Project Duration (period)	30	
Discount Factor	7.0%	
NPV of Capital Costs		$7,674,445
NPV of Annual O&M Costs		$21,592
NPV of Periodic Costs		$312,901
Total Estimated Costs (NPV)		**$8,008,938**

Notes:

[A] *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* , EPA 540-R-00-002

Alternative M4—Shallow Hot Spot Removal and Thin Cover

Capital Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Excavation Costs				
Clearing the Site	Acre	6.00	$1,217	$7,302
Load, Haul, and Disposal of Debris	CY	19,360	$24	$467,157
Excavate Contaminated Soil	CY	11,448	$47	$538,056
Load, Haul and Disposal of Non-Hazardous Materials to Landfill	CY	-	$105	$0
Load, Haul and Disposal at Subtitle C Landfill	CY	17,172	$220	$3,777,840
Sheet pile	SF	2,250	$18	$41,509
Dewatering and disposal	days	30	$650	$19,500
Treatment of pumped water	gpm-days	30	$1,593	$47,795
			Subtotal:	$4,899,159
Cover Costs				
Commercial Pelitized Clay Placement	CY	3,065	$300	$919,600
			Subtotal:	$919,600
Site Restoration				
Habitat Loss Mitigation	Acre	7.6	$100,000	$760,000
Obtain, Haul and Place Backfill	CY	11,448	$54	$618,192
First Year Maintenance	MO	12	$20,000	$240,000
Re-establish Marsh Vegetation	AC	6.00	$3,480	$20,880
			Subtotal:	$1,639,072
Mobilization/Demobilization +Staging area+dewatering area	LS	1	$691,430	$691,430
Site preparation (15 feet wide approach road)	LF	3,000	$82	$247,275
15 feet wide berm construction	LF	100	$75	$7,500
Pre-design investigation	LS	1	$50,000	$50,000
			Subtotal	$946,205
		Total Direct Capital Costs:		$8,404,036
Indirect Capital Costs				
Engineering[A]	% of Direct Costs	20%		$1,680,807
Project Management[A]	% of Direct Costs	10%		$840,404
Construction Oversight[A]	% of Direct Costs	15%		$1,260,605
Scope & Bid Contingency (15% Each)[A]	% of Direct Costs	30%		$2,521,211
		Total Indirect Capital Costs:		$6,303,027
Total Capital Costs				**$14,707,063**

Operating Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Annual Direct Costs				
Site Maintenance	per Visit	4	$300	$1,200
		Total Annual Direct Costs:		$1,200
Annual Indirect Costs				
Project Management[A]	% of Direct Costs	5%	$1,200	$60
Technical Support[A]	% of Direct Costs	10%	$1,200	$120
Contingency[A]	% of Direct Costs	30%	$1,200	$360
		Total Annual Indirect Costs:		$540
		Total Annual Costs:		$1,740

Periodic Costs

Five Year Reviews	each	6	$50,000	$300,000
Annual monitoring for first 5 years	each	5	$50,000	$250,000
		Total Periodic Costs:		$550,000

Net Present Value Analysis

Project Duration (period)	30	
Discount Factor	7.0%	
NPV of Capital Costs		$14,707,063
NPV of Annual O&M Costs		$21,592
NPV of Periodic Costs		$312,901
Total Estimated Costs (NPV)		**$15,041,556**

Notes:

[A] *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, EPA 540-R-00-002

Alternative M5—Extended Shallow Removal and Thin Cover

Capital Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Excavation Costs				
Clearing the Site	Acre	6.00	$1,217	$7,302
Load, Haul, and Disposal of Debris	CY	19,360	$24	$467,157
Excavate Contaminated Soil	CY	17,618	$47	$828,027
Load, Haul and Disposal at Subtitle D Landfill	CY	6,970	$105	$731,808
Load, Haul and Disposal at Subtitle C Landfill	CY	15,972	$220	$3,513,840
Sheet pile	SF	4,500	$18	$83,018
Dewatering and disposal	days	60	$650	$39,000
Treatment of pumped water	days	60	$1,593	$95,590
			Subtotal	$5,765,742
Cover Costs				
Commercial Pelitized Clay Placement	CY	1,129	$300	$338,800
			Subtotal	$338,800
Site Restoration				
Habitat Loss Mitigation	Acres	7.6	$100,000	$760,000
Obtain, Haul and Place Backfill	CY	19,941	$54	$1,076,803
Channel Armor Placement	LF	900	$100	$90,000
First Year Maintenance	MO	12	$20,000	$240,000
Re-establish Marsh Vegetation	AC	6.00	$3,480	$20,880
			Subtotal	$2,187,683
Mobilization/Demobilization +Staging area+dewatering area	LS	1	$937,717	$937,717
Site preparation (15 feet wide approach road)	LF	3,000	$82	$247,275
15 feet wide berm construction	LF	100	$75	$7,500
Pre-design investigation	LS		$50,000	$0
			Subtotal	$1,192,492
		Total Direct Capital Costs:		$9,484,717
Indirect Capital Costs				
Engineering[A]	% of Direct Costs	20%		$1,896,943
Project Management[A]	% of Direct Costs	10%		$948,472
Construction Oversight[A]	% of Direct Costs	15%		$1,422,708
Scope & Bid Contingency (15% Each)[A]	% of Direct Costs	30%		$2,845,415
		Total Indirect Capital Costs:		$7,113,538
Total Capital Costs				**$16,598,255**

Operating Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Annual Direct Costs				
Site Maintenance	per Visit	4	$300	$1,200
		Total Annual Direct Costs:		$1,200
Annual Indirect Costs				
Project Management[A]	% of Direct Costs	5%	$1,200	$60
Technical Support[A]	% of Direct Costs	10%	$1,200	$120
Contingency[A]	% of Direct Costs	30%	$1,200	$360
		Total Annual Indirect Costs:		$540
		Total Annual Costs:		$1,740

Periodic Costs

Five Year Site Inspections and Reviews	each	5	$50,000	$250,000
Annual monitoring for 4 years	each	4	$50,000	$200,000
		Total Periodic Costs:		$450,000

Net Present Value Analysis

Project Duration (period)	30	
Discount Factor	7.0%	
NPV of Capital Costs		$16,598,255
NPV of Annual O&M Costs		$21,592
NPV of Periodic Costs		$241,603
Total Estimated Costs (NPV)		**$16,861,449**

Notes:

[A] *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* , EPA 540-R-00-002

Alternative M6—Extended Deep Removal and Thin Cover

Capital Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Excavation Costs				
Clearing the Site	Acre	6.00	$1,217	$7,302
Load, Haul, and Disposal of Debris	CY	19,360	$24	$467,157
Excavate Contaminated Soil	CY	22,470	$47	$1,056,109
Load, Haul and Disposal at Subtitle D Landfill	CY	9,293	$105	$975,744
Load, Haul and Disposal at Subtitle C Landfill	CY	19,766	$220	$4,348,608
Sheet pile	SF	4,500	$18	$83,018
Dewatering and disposal	days	60	$650	$39,000
Treatment of pumped water	days	60	$1,593	$95,590
			Subtotal:	$7,072,528
Cover Costs				
Commercial Pelitized Clay Placement	CY	1,129	$300	$338,800
			Subtotal:	$338,800
Site Restoration				
Habitat Loss Mitigation	Acres	2.8	$100,000	$280,000
Obtain, Haul and Place Backfill	CY	22,470	$54	$1,213,402
First Year Maintenance	MO	12	$20,000	$240,000
Re-establish Marsh Vegetation	AC	4.60	$3,480	$16,008
			Subtotal:	$1,749,410
Mobilization/Demobilization +Staging area+dewatering area	LS	1	$1,131,437	$1,131,437
Site preparation (15 feet wide approach road)	LF	3,000	$82	$247,275
15 feet wide berm construction	LF	100	$75	$7,500
Pre-design investigation	LS	1	$50,000	$50,000
			Subtotal	$1,386,212
			Total Direct Capital Costs:	$10,546,950
Indirect Capital Costs				
Engineering[A]	% of Direct Costs	20%		$2,109,390
Project Management[A]	% of Direct Costs	10%		$1,054,695
Construction Oversight[A]	% of Direct Costs	15%		$1,582,042
Scope & Bid Contingency (15% Each)[A]	% of Direct Costs	30%		$3,164,085
			Total Indirect Capital Costs:	$7,910,212
Total Capital Costs				**$18,457,162**

Operating Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Annual Direct Costs				
Site Maintenance	per Visit	4	$300	$1,200
			Total Annual Direct Costs:	$1,200
Annual Indirect Costs				
Project Management[A]	% of Direct Costs	5%	$1,200	$60
Technical Support[A]	% of Direct Costs	10%	$1,200	$120
Contingency[A]	% of Direct Costs	30%	$1,200	$360
			Total Annual Indirect Costs:	$540
			Total Annual Costs:	$1,740

Periodic Costs

Five Year Site Inspections and Reviews	each	5	$50,000	$250,000
Annual monitoring for 4 years	each	4	$50,000	$200,000
			Total Periodic Costs:	$450,000

Net Present Value Analysis

Project Duration (period)	30	
Discount Factor	7.0%	
NPV of Capital Costs		$18,457,162
NPV of Annual O&M Costs		$21,592
NPV of Periodic Costs		$169,361
Total Estimated Costs (NPV)		**$18,648,115**

Notes:

[A] *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, EPA 540-R-00-002

Alternative M7—Complete Removal

Capital Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Excavation Costs				
Clearing the Site	Acre	6.00	$1,217	$7,302
Load, Haul, and Disposal of Debris	CY	19,360	$24	$467,157
Excavate Contaminated Soil	CY	31,182	$47	$1,465,573
Load, Haul and Disposal at Subtitle D Landfill	CY	18,005	$105	$1,890,504
Load, Haul and Disposal at Subtitle C Landfill	CY	19,766	$220	$4,348,608
Sheet pile	SF	4,500	$18	$83,018
Dewatering and disposal	days	60	$650	$39,000
Treatment of pumped water	days	60	$1,593	$95,590
			Subtotal:	$8,396,752
Site Restoration				
Obtain, Haul and Place Backfill	CY	24,856	$54	$1,342,224
First Year Maintenance	MO	12	$20,000	$240,000
Re-establish Marsh Vegetation	AC	6.00	$3,480	$20,880
			Subtotal:	$1,603,104
Mobilization/Demobilization +Staging area+dewatering area	LS	1	$1,479,215	$1,479,215
Site preparation (15 feet wide approach road)	LF	3,000	$82	$247,275
15 feet wide berm construction	LF	100	$75	$7,500
Pre-design investigation	LS	1	$50,000	$50,000
			Subtotal	$1,733,990
		Total Direct Capital Costs:		$11,733,846
Indirect Capital Costs				
Engineering[A]	% of Direct Costs	20%		$2,346,769
Project Management[A]	% of Direct Costs	10%		$1,173,385
Construction Oversight[A]	% of Direct Costs	15%		$1,760,077
Scope & Bid Contingency (15% Each)[A]	% of Direct Costs	30%		$3,520,154
		Total Indirect Capital Costs:		$8,800,384
Total Capital Costs				**$20,534,230**

Operating Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Annual Direct Costs				
Site Maintenance	per Visit	4	$300	$1,200
		Total Annual Direct Costs:		$1,200
Annual Indirect Costs				
Project Management[A]	% of Direct Costs	5%	$1,200	$60
Technical Support[A]	% of Direct Costs	10%	$1,200	$120
Contingency[A]	% of Direct Costs	30%	$1,200	$360
		Total Annual Indirect Costs:		$540
		Total Annual Costs:		$1,740

Periodic Costs

Five Year Site Inspections and Reviews	each	1	$50,000	$50,000
Annual monitoring for 4 years	each	4	$50,000	$200,000
		Total Periodic Costs:		$250,000

Net Present Value Analysis

Project Duration (period)	30	
Discount Factor	7.0%	
NPV of Capital Costs		$20,534,230
NPV of Annual O&M Costs		$21,592
NPV of Periodic Costs		$169,361
Total Estimated Costs (NPV)		**$20,725,183**

Notes:

[A] *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* , EPA 540-R-00-002

Alternative R1—No Action

Capital Costs		
	Total Capital Costs:	**$0**
Operating Costs		
	Total Annual Costs:	$0
	Total Periodic Costs:	$0
Net Present Value Analysis		
Project Duration (period)	30	
Discount Factor	7.0%	
NPV of Capital Costs		$0
NPV of Annual O&M Costs		$0
NPV of Periodic Costs		$0
Total Estimated Costs (NPV)		**$0**

Notes:

[A] *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* , EPA 540-R-00-00

Alternative R2—Monitored Natural Recovery

Capital Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
MNR Initiation				
Plan Development	LS	1	50,000	50,000
Baseline Bathymetric Survey	LS	1	50,000	50,000
Baseline Coring and Analysis	days	2	10,000	20,000
			Subtotal	$120,000
Contingency	25%			$30,000
			Subtotal	$150,000
Project Management[A]	10%			$15,000
MNR Plan	LS	1	$50,000	$50,000
Baseline Report	LS	1	$25,000	$25,000
			Subtotal	$90,000
Total Capital Costs				**$240,000**

Operating Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Annual Operation & Maintenance				
(Included as Periodic Costs)				
			Total Annual Costs:	$0

Periodic Costs

Five Year Monitoring and Reporting	each	6	$90,000	$540,000
Annual monitoring for 4 years	each	4	$70,000	$280,000
			Total Periodic Costs:	$820,000

Net Present Value Analysis

Project Duration (period)	30	
Discount Factor	7.0%	
NPV of Capital Costs		$240,000
NPV of Annual O&M Costs		$0
NPV of Periodic Costs		$431,308
Total Estimated Costs (NPV)		**$671,308**

Notes:

[A] *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* , EPA 540-R-00-002

Alternative R3—Shallow Dredge and Thin Cap

Capital Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Dredging Costs				
Dredge from shore	CY	2,323	$75	$174,240
Load, Haul and Disposal of Non-Hazardous Materials to Landfill	CY	2,323	$105	$243,936
Dewatering of dredged materials in a separate barge	days	10	$500	$5,000
			Subtotal	$423,176
Capping Costs				
Obtain, Haul and Place Backfill/Cap	CY	1,936	$100	$193,600
Thin Cap Placement	CY	1,371	$300	$411,400
			Subtotal	$605,000
MNR Initiation				
Baseline Bathymetric Survey	LS	1	50,000	50,000
Baseline Coring and Analysis	days	4	10,000	40,000
MNR Plan	LS	1	$50,000	$50,000
			Subtotal:	$140,000
Mobilization/Demobilization				
Site Preparation and Materials Staging	LS	1	$318,829	$318,829
Silt curtain	LF	2,000	$5	$10,000
			Subtotal	$328,829
			Total Direct Capital Costs:	$1,497,005
Indirect Capital Costs				
Engineering[A]	% of Direct Costs	20%		$299,401
Project Management[A]	% of Direct Costs	10%		$149,701
Construction Oversight[A]	% of Direct Costs	15%		$224,551
Scope & Bid Contingency (15% Each)[A]	% of Direct Costs	30%		$449,102
			Total Indirect Capital Costs:	$1,122,754
Total Capital Costs				**$2,619,759**

Operating Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Annual Operation & Maintenance				
(Included as Periodic Costs)				
			Total Annual Costs:	$0

Periodic Costs

Five Year Monitoring and Reporting	each	6	$90,000	$540,000
Annual monitoring for 4 years	each	4	$70,000	$280,000
			Total Periodic Costs:	$820,000
Project Duration (period)		30		
Discount Factor		7.0%		
NPV of Capital Costs				$2,619,759
NPV of Annual O&M Costs				$0
NPV of Periodic Costs				$151,047
Total Estimated Costs (NPV)				**$2,770,806**

Notes:

[A] *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* , EPA 540-R-00-002

Alternative R4—Extended Shallow Dredge

Capital Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Dredging Costs				
Dredge from Barge	CY	7,260	$150	$1,089,000
Load, Haul and Disposal at Subtitle D Landfill	CY	7,260	$105	$762,300
Dewatering of dredged materials in a separate barge	days	42	$500	$21,000
Dredge Depth Measurement/Confirmation	LS	1	$40,000	$40,000
			Subtotal:	$1,913,600
Capping Costs				
Obtain, Haul and Place Cap	CY	6,050	$100	$605,000
Final Elevation Confirmation Survey	LS	1	$100,000	$100,000
Baseline Coring and Analysis	days	1	$10,000	$10,000
			Subtotal:	$715,000
Mobilization/Demobilization				
Site preparation	LS	1	$498,170	$498,170
Silt curtain for dredging	LF	2,000	$5	$10,000
			Subtotal	$508,170
		Total Direct Capital Costs:		$3,136,770
Indirect Capital Costs				
Engineering[A]	% of Direct Costs	20%		$627,354
Project Management[A]	% of Direct Costs	10%		$313,677
Construction Oversight[A]	% of Direct Costs	15%		$470,516
Scope & Bid Contingency (15% Each)[A]	% of Direct Costs	30%		$941,031
		Total Indirect Capital Costs:		$2,352,578
Total Capital Costs				**$5,489,348**

Operating Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Annual Operation & Maintenance				
(Included as Periodic Costs)				
		Total Annual Costs:		$0

Periodic Costs

Five Year Monitoring and Reporting	each	6	$90,000	$540,000
Annual monitoring for 4 years	each	4	$70,000	$280,000
				$820,000

Net Present Value Analysis

Project Duration (period)	30	
Discount Factor	7.0%	
NPV of Capital Costs		$5,489,348
NPV of Annual O&M Costs		$0
NPV of Periodic Costs		$64,169
Total Estimated Costs (NPV)		**$5,553,517**

Notes:

[A] *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* , EPA 540-R-00-002

Alternative R5—Deep Dredge and MNR

Capital Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Dredging Costs				
Dredge from Barge	CY	19,360	$150	$2,904,000
Load, Haul and Disposal at Subtitle D Landfill	CY	19,360	$105	$2,032,800
Dewatering of dredged materials in a separate barge	days	56	$500	$28,000
Dredge Depth Measurement/Confirmation	LS	1	$20,000	$20,000
			Subtotal:	$4,986,100
MNR Initiation				
Baseline Bathymetric Survey	LS	1	50,000	50,000
Baseline Coring and Analysis	days	4	10,000	40,000
MNR Plan	LS	1	$50,000	$50,000
Baseline Report	LS	1	$25,000	$25,000
			Subtotal:	$165,000
Mobilization/Demobilization				
Site preparation	LS	1	$937,733	$937,733
Silt curtain for dredging	LF	2,000	$5	$10,000
			Subtotal	$947,733
		Total Direct Capital Costs:		$6,098,833
Indirect Capital Costs				
Engineering[A]	% of Direct Costs	20%		$1,219,767
Project Management[A]	% of Direct Costs	10%		$609,883
Construction Oversight[A]	% of Direct Costs	15%		$914,825
Scope & Bid Contingency (15% Each)[A]	% of Direct Costs	30%		$1,829,650
		Total Indirect Capital Costs:		$4,574,124
Total Capital Costs				**$10,672,957**

Operating Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Annual Operation & Maintenance				
(Included as Periodic Costs)				
		Total Annual Costs:		$0

Periodic Costs

Five Year Monitoring and Reporting	each	6	$90,000	$540,000
Annual monitoring for 4 years	each	4	$70,000	$280,000
		Total Periodic Costs:		$820,000

Net Present Value Analysis

Project Duration (period)	30	
Discount Factor	7.0%	
NPV of Capital Costs		$10,672,957
NPV of Annual O&M Costs		$0
NPV of Periodic Costs		$194,204
Total Estimated Costs (NPV)		**$10,867,160**

Notes:

[A] *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* , EPA 540-R-00-002

Alternative R6—Deep Dredge and Cover

Capital Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Dredging Costs				
Dredge from Barge	CY	19,360	$150	$2,904,000
Load, Haul and Disposal at Subtitle D Landfill	CY	19,360	$105	$2,032,800
Dewatering of dredged materials in a separate barge	days	56	$500	$28,000
Dredge Depth Measurement/Confirmation	LS	1	$40,000	$40,000
			Subtotal:	$5,006,100
Capping Costs				
Obtain, Haul and Place Backfill/Cap	CY	16,133	$100	$1,613,333
Final Elevation Confirmation Survey	LS	1	$100,000	$100,000
Baseline Coring and Analysis	days	-	$10,000	$0
			Subtotal:	$1,713,333
Mobilization/Demobilization				
Site preparation	LS	1	$937,733	$937,733
Silt curtain for dredging	LF	2,000	$5	$10,000
			Subtotal	$947,733
		Total Direct Capital Costs:		$7,667,166
Indirect Capital Costs				
Engineering[A]	% of Direct Costs	20%		$1,533,433
Project Management[A]	% of Direct Costs	10%		$766,717
Construction Oversight[A]	% of Direct Costs	15%		$1,150,075
Scope & Bid Contingency (15% Each)[A]	% of Direct Costs	30%		$2,300,150
		Total Indirect Capital Costs:		$5,750,374
Total Capital Costs				**$13,417,540**

Operating Costs

COST COMPONENT	UNIT	QUANTITY	UNIT COST	TOTAL COST
Annual Operation & Maintenance				
(Included as Periodic Costs)				
			Total Annual Costs:	$0
Periodic Costs				
Five Year Monitoring and Reporting	each	1	$90,000	$90,000
				$90,000

Net Present Value Analysis

Project Duration (period)	30	
Discount Factor	7.0%	
NPV of Capital Costs		$13,417,540
NPV of Annual O&M Costs		$0
NPV of Periodic Costs		$64,169
Total Estimated Costs (NPV)		**$13,481,709**

Notes:

[A] *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, EPA 540-R-00-002

Appendix F

Technology Applications for OU-3

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MEMO

To:
Betsy Henry (Exponent)
Mark Bryant (Exponent)

Copies:
File

From:
Philip Spadaro
Kristi Maitland
Shannon Dunn

Date:
June 25, 2008

ARCADIS BBL Project No.:
NJ000514003

Subject:
Technology Applications for Operable Unit 3
Horseshoe Road/ARC Superfund Sites

1 Introduction

A Technical Memorandum was submitted to the U.S. Environmental Protection Agency (USEPA) in 2006 (Exponent, 2006) that screened the various technologies for sediment remediation and then developed remedial alternatives that were applicable to Operable Unit 3 (OU-3) of the Horseshoe Road and Atlantic Resources Corporation (ARC) Superfund Sites (collectively, the Sites) located in Sayreville, Middlesex County, New Jersey. The proposed remedial alternatives that were retained for inclusion in the Feasibility Study (FS) include dredging/excavation, capping, monitored natural recovery (MNR), and/or a combination of these three primary remedial technologies for contaminated sediments.

In a letter dated June 11, 2007, USEPA addressed the Remedial Action Objectives (RAOs) and Preliminary Remediation Goals (PRGs) for the site and provided some comments regarding the remedial technologies proposed for OU-3 (Prince, 2007). In that letter, USEPA commented on several of the proposed remedial technologies, including a concern that MNR may not be able to achieve the RAOs for the site. This document has been prepared to provide additional information on the three primary sediment remediation technologies (MNR, capping, and dredging) and how they could be successfully implemented at OU-3 at the Horseshoe Road/ARC Superfund Sites.

2 Monitored Natural Recovery

2.1 Introduction

The remedial alternatives proposed for OU-3 that include Monitored Natural Recovery (MNR) as the remedy or part of the remedy are as follows: M2, M3, R2, and R5 (Exponent, 2007). MNR is defined by USEPA as a "…remedy for contaminated sediment that typically uses ongoing, naturally occurring processes to contain, destroy, or reduce the bioavailability or toxicity of contaminants in sediment" (USEPA, 2005). MNR can be implemented as a stand-alone technology or in conjunction with other active measures, such as source control or source removal. MNR is a fundamental component of the USEPA's Contaminated Sediment Management Strategy (USEPA, 1998) and is a USEPA-accepted technology that has been selected as a key component of the cleanup method for contaminated sediments at many Superfund sites (USEPA, 2005). Table 1 provides a summary of sediment remediation projects where MNR has been applied successfully as a key component of the remedy.

MNR relies on natural recovery processes to achieve site-specific remediation objectives within a time frame that may be longer than other active methods but is still reasonable in comparison. Natural recovery processes for contaminated sediment are well documented. The USEPA defines natural processes as the following physical, biological, or chemical mechanisms that reduce risks associated with chemicals of potential concern (COPCs) in sediment (USEPA, 2005):

- physical processes: sedimentation, advection, diffusion, dilution, bioturbation, and volatilization
- biological processes: biodegradation, biotransformation, phytoremediation, and biological stabilization
- chemical processes: oxidation/reduction, stabilization, and sorption

The physical, biological, and chemical processes that may contribute to the natural recovery of sediment are shown graphically on Figure 1. Risks associated with COPCs in sediment may be reduced through MNR in one or more of the following ways (USEPA, 2005):

- the mixing in of cleaner sediments or covering of the surface by cleaner sediments, resulting in a reduction of the concentrations of COPCs in surface sediment
- biodegradation or chemical transformation, resulting in the conversion of a COPC to a less toxic form
- sorption to sediment, resulting in reduced COPC mobility and bioavailability

MNR is a technology based on understanding and quantitatively documenting the natural processes. Rather than implementing engineered technologies, MNR involves evaluating natural processes that reduce risk to acceptable levels (USEPA, 2001). The benefits of MNR (USEPA, 1999) are that:

- As an in-situ process, MNR generates less volume of remediation wastes, reduces potential for cross-media transfer of contaminants, reduces risk of human exposure to contaminants and contaminated media, and reduces risks to ecological receptors due to exposure to contaminants and contaminated media.

- MNR can result in in-situ destruction of contaminants.

- MNR results in less intrusion, including less disruption of sediment ecosystems, because few surface disturbances are required.

- MNR is flexible and is potentially applicable to all or part of a site, depending on site conditions and remedial action objectives.

- MNR can be used in conjunction with other, more active technologies.

- MNR results in remediation costs that may be lower overall than the cost of more active remediation.

While all three potential remedy approaches (removal, capping, and MNR) should be considered at every site where they might be appropriate, some site conditions are especially conducive to MNR. Some of these conditions already exist at OU-3. The following is a list of site conditions that may favor the use of MNR as a remedy or as part of a remedy (USEPA, 2005):

- Anticipated land uses or new site structures are compatible with natural recovery.

- Natural recovery processes have a reasonable degree of certainty to continue at rates that will contain, destroy, or reduce the bioavailability or toxicity of COPCs within an acceptable time frame.

- Human exposure is expected to be low and/or can be reasonably controlled by institutional controls.

- Reasonably stable sediment bed that is likely to remain so.

- Well-armored or cohesive sediment that is resistant to resuspension.

- Concentrations of COPCs in biota and in the biologically active zone of sediment are moving towards risk-based goals on their own.

- COPCs already readily biodegrade or transform to lower toxicity forms.

- Concentrations of COPCs are low and cover diffuse areas.

- Bioaccumulation rate of COPCs is low.

2.2 Evaluating MNR as a Remedy

All sediment site remedies use natural recovery to some extent because the natural processes are always occurring whether or not a cleanup is underway. However, these natural processes may transfer, reduce, or even increase risk at a site. The factors that distinguish MNR as an actual remedy are the presence of unacceptable risk, the ongoing burial/degradation/transformation/dispersion of the COPCs, and the establishment of a cleanup level that MNR is expected to meet in a particular time frame (USEPA, 2005).

Based on USEPA guidance (USEPA, 2005), the following information and conditions are generally needed to support MNR as a remedial technology at a site:

- a detailed understanding of the natural processes that are affecting sediment and contaminants at the site
- a predictive tool (modeling or extrapolation of existing data) to predict future effects of those natural processes
- a means to control any significant ongoing contaminant sources
- ability to evaluate the ongoing risks during the recovery period and exposure control
- ability to monitor the natural processes and/or concentrations of contaminants in sediment or biota to determine whether recovery is occurring at the expected rate.

The USEPA Office of Research and Development (ORD) is currently in the process of developing a technical resource document specifically for MNR in sediments which may include suggested protocols for evaluation. In the meantime, members of the joint industry-USEPA Sediments Action Team of the Remedial Technologies Development Forum (RTDF) have developed a series of working papers regarding MNR. These papers can be found at http://www.rtdf.org/public/sediment/mnrpapers.htm (Davis et al. 2004, Dekker et al. 2004, Erickson et al 2004, Magar et al. 2004, Patmont et al. 2004). The USEPA and the Sediment Management Working Group (SMWG) have determined that a weight-of-evidence approach is necessary to evaluate the use of MNR at contaminated sediment sites. Five primary lines of evidence have been identified as key in the framework for the evaluation process (Davis et al. 2004). USEPA guidance (USEPA, 2005) notes that not all lines of evidence are appropriate for every site, but multiple lines are required to support MNR as a remedial technology.

The five key lines of evidence in the evaluation framework include (Davis et al. 2004):

- ***Characterize contamination sources and controls*** – This line of evidence includes characterizing both historic and current contaminant loading to the sediment site. During this step, it is important to differentiate between and evaluate external upland/watershed sources versus internal sources with legacy sediments. Source characterization can be difficult and expensive because of the complexities often associated with the contaminant loading processes.

- ***Characterize fate and transport processes*** – An understanding of environmental processes affecting sediment and contaminants is required to support an MNR evaluation. Processes affecting contaminants include burial, advection and dispersion, partitioning, gas phase exchange, mechanical or molecular diffusion, and abiotic and biotic transformation reactions. Key processes affecting sediment transport include settling/deposition, long-term burial, erosion, flocculation and aggregation, biological and physical mixing in the bed, bed consolidation, weathering and diagenesis of sediment particles, and bed sorting and grading processes arising from variations in flow velocity and transport capacity of the water column.

- ***Establish historical record for contaminants in sediments*** – The primary objective of this line of evidence is to evaluate reduction in chemical exposure using temporal trends in sediment chemical concentration data. Data from past sampling of surface sediments, waters, and/or sources can be compiled to establish an historical record for the contaminated sediments. Historical trends in contaminant release to a site can also be inferred from sediment core analyses and/or radioisotope dating of the cores.

- ***Corroborate MNR based on biological endpoint trends*** – The purpose of this line of evidence is to determine whether any reduction of COPCs in the sediment results in any improvements in the biological data. The biological endpoints are site-dependant and often include fish or benthic community analysis, fish or invertebrate tissue chemistry, sediment toxicity bioassays, and histopathology/biomarkers.

- ***Develop acceptable and defensible predictive tools*** – This final line of evidence is to determine whether the observed reductions in sediment and biological risks can be expected to continue or be augmented in the future with additional source controls. At most sites, the fate and transport processes driving recovery may be complex and change with time, so extrapolation of historical trends may not be enough to predict future site conditions. In most cases, a well-constructed computer model can be a useful tool to predict the future behavior of the system at a sediment site.

2.3 Potential Advantages and Disadvantages

The two main advantages of MNR are its non-invasive nature and its relatively low implementation cost. Due to its non-invasive nature that typically involves no man-made physical disruption to the site, MNR may be an important advantage for sensitive environments where harm to the ecological community may outweigh the risk reduction of a cleanup. Implementation costs are primarily associated with long-term monitoring, but may also include the cost for the public education process regarding MNR and the cost of implementing institutional controls. Additionally, the costs for the initial site characterization and modeling can be extensive depending on the site (USEPA, 2005).

The two main disadvantages of MNR are that it leaves the COPCs in place and that its progress can be slow in comparison to other remedies. There is a risk of re-exposure to COPCs with any remedy that leaves untreated contaminants in place. If a sediment bed is significantly disturbed by unexpectedly strong natural or man-made forces during the natural burying process, some buried COPCs may be dispersed or re-exposed. While the time frame for MNR may be slower than the active remedies, time frames for various remedial alternatives may overlap when uncertainties are factored into the comparison. Some of the active remedies may have longer design periods and implementation times which should also be factored into the comparison (USEPA, 2005).

2.4 Specific Application of MNR to OU-3 at the Horseshoe Road/ARC Superfund Sites

Based on USEPA guidance, there are five components involved in evaluating the feasibility of MNR for contaminated sediment (USEPA, 2002):

- COPC fate and transport;
- Conceptual and predictive modeling of COPC concentration changes over time;
- Source control;
- Limited COPC exposure during recovery, to extent possible; and
- Ability to monitor sediment recovery.

Each of these is discussed in the following sections.

2.4.1 COPC Fate and Transport

COPC fate and transport within the proposed MNR areas were evaluated. The evaluation included:

- Surface sediment concentration of COPCs;
- COPC concentration profiles with depth;
- Sedimentation rates;
- Resuspension and advection;
- Diffusion, including bioturbation;
- Degradation of organic compounds; and
- Sediment/water partitioning.

2.4.1.1 ***Surface Sediment Concentrations***

The surface and subsurface sediment data were evaluated for arsenic and mercury. Areas selected for MNR contained relatively low surface sediment concentrations of arsenic and mercury. Surface sediment concentrations of COPCs indicate MNR is a reasonable and feasible remedial action for the proposed MNR areas.

2.4.1.2 ***COPC Concentration Profiles with Depth***

In the areas of proposed MNR, arsenic and mercury concentrations with depth were evaluated.

In the marsh, sample locations SDM09, SDM10, and SDM11 for arsenic and SDM10 and SDM11 for mercury contained subsurface maximum concentrations. The remaining marsh locations generally had the maximum arsenic and mercury concentration at the surface.

In the river, sample locations RSD03, RSD04, RSD05, RSD07, RSD08, RSD11, RSD12, and RSD13 for arsenic and RSD03, RSD04, RSD05, RSD06, RSD08, RSD10, RSD13, and RSD15 for mercury contained subsurface maximum concentrations. The remaining river locations generally had the maximum arsenic and mercury concentrations at the surface.

The presence of subsurface maximum arsenic and mercury concentrations indicates that generally the surface sediment concentrations are decreasing with time and that MNR is feasible in this area.

2.4.2 Sedimentation Rates

Sedimentation rates were evaluated using literature for the lower Raritan River. The lower Raritan River is a depositional environment (Motta et al., 1983; Renwick and Ashley, 1984; Bokuniewicz and Coch, 1986; Renwick and Motta, 1992; Ashely and Motta, 1992). The Raritan River estuary is a drowned river valley that was submerged by post-glacial sea level rise. The Raritan River estuary appears to be a trap for upstream sediment (sediment being carried in the Raritan River) and ocean sediment (sediment carried into the river on high tide) based on river velocity, bed load, and suspended sediment load measurements. Most fine grained sediment accumulates in the lower estuary (the site is located within the lower estuary). Coarse grained sediment in the lower estuary primarily accumulates in the river channel. The channels in the lower Raritan River do not appear to migrate much with time. Maps from the early 19th century show little difference compared to the current channels. This indicates that sediment accretion may consist primarily of vertical accretion rather than point-bar deposition.

The wetlands also appear to be an area of deposition. Aerial observations during spring tides indicate that sediment laden water floods much of the wetlands (Renwick and Ashley, 1984). In the vicinity of the site, deposition of fine grained sediment occurs in the river and the marshes fringing the river (Renwick and

Motta, 1992). The Raritan River estuary consists of salt marshes, tidal flats, and tidal channels where sediment accumulates (Renwick and Motta, 1992).

2.4.2.1 ***Resuspension and Advection***

Resuspension and advection were evaluated using literature for the lower Raritan River. As discussed in the section above, the lower Raritan River appears to be a depositional environment. Although there may be resuspension and advection occurring in the lower Raritan River, it is still an area of net deposition.

2.4.2.2 ***Diffusion***

The diffusion aspect of MNR is primarily an evaluation of bioturbation rates. There are no site specific data on bioturbation rates. However, bioturbation in estuarine sediments is well documented (Matisoff et al., 1999; Bosworth and Thibodeaux, 1990).

The life activities of benthic organisms are capable of altering the biological, physical, and chemical properties of sediments (Rhoads, 1974; Guinasso and Schink, 1975; Pryor, 1975; Rice, 1986; Aller, 1988). These activities, such as burrowing and irrigation, tend to increase the exchange of solutes within the bioturbated zone and between sediment and overlying water (Rhoads, 1974; Schink and Guinasso, 1977; Aller and Yingst, 1985; Kristensen et al*.,* 1991). Bioturbation can also physically rework the sediment and increase the resuspension of sediment into the water column (Aller, 1978; Nowell et al*.,* 1981; McCall et al*.,* 1986; Bosworth and Thibodeaux, 1990; and Davis, 1993). The transport of solutes and solids within the sediment and across the sediment-water interface influences many natural biogeochemical cycles, as well as the movement of pollutants in sediments. The intensity of bioturbation depends on the benthic community, in which many characteristics may vary spatially, such as the concentration of organisms, the size of the animals, and the life activities of the species present (Rhoads, 1974; Myers, 1977; Aller, 1982 and 1988; Matisoff et al*.,* 1985; Aller and Aller, 1992; Marinelli, 1994).

In the absence of burrowing organisms in the sediment or the absence of frequent resuspension of sediment, the supply of oxygen is limited to molecular diffusion through the sediment-water interface. Oxygen will usually penetrate ~2-3 mm into the sediment by molecular diffusion (Aller, 1994). Thus, within a few millimeters of the sediment-water interface, the sediment will be anoxic. Bioturbation in the sediment dramatically increases the supply of oxygen and other solutes to the sediment and, as a result, greatly affects reduction-oxidation (redox) pathways within the sediment. Metals speciation is dependent, in part, on redox conditions.

The standard profile of sediment respiration consists of a series of oxidants that are consumed in order of free energy release, that order being: oxygen, nitrate, manganese, iron, sulfate, and carbon dioxide (Berner, 1980; Froelich et al., 1979; Stumm and Morgan, 1979). The explanation given for this succession is the metabolic free energy yield of the oxidants (Berner, 1980; Froelich et al., 1979; Stumm and Morgan, 1970). Generally, the lower free energy oxidants will not be utilized until the higher-energy oxidants have been consumed. If molecular diffusion from the overlying water column were the only source of these oxidants to the sediment, the major oxidant profile would be one dimensional (Aller, 1982; Aller, 1988; Berner, 1980). The presence of invertebrate infauna, however, introduces burrows into the sediment. Typically, burrows are tube-shaped voids in the sediment and are usually irrigated by the inhabitant with overlying water. Depending on the permeability of the burrow walls, the burrows may introduce oxygen and other oxidants into the sediment. Ventilated burrows extend the sediment-water interface and greatly increase the surface area-to-volume ratio of this interface (Aller, 1988).

When the burrows are ventilated, oxygen radially diffuses into the anoxic sediment (Aller, 1988). This diffusion will locally alter the redox profile around the burrow. Burrows change the rate of oxygen supply from a one-dimensional system of molecular diffusion to a two-dimensional system of radial diffusion (Aller, 1988). Thus, radial diffusion enhances the supply of oxygen to the sediment. Radial diffusion from burrows dramatically alters redox pathways in the sediment in comparison to non-bioturbated sediment. Oxygen penetrates approximately 70-80% farther into sediments around burrows than at surficial sediment-water interfaces, assuming same sediment reactivity (Aller, 1988).

2.4.2.3 ***Degradation of Organic Compounds***

Degradation of organic compounds was not evaluated because metals are the primary constituents of concern.

2.4.2.4 ***Sediment/Water Partitioning***

Site-specific partition coefficients are not available.

2.4.3 SEDCAM Modeling

The SEDCAM model, which is accepted and used by USEPA Region 10 and Washington State Department of Ecology, was used to evaluate the change in sediment concentrations with time (Jacobs et al., 1988; Ecology, 1991). SEDCAM evaluates source loading, sediment deposition, and chemical specific degradation rates. The concentration at some time after natural recovery begins can be estimated as follows (Jacobs et al., 1988):

$$C(t) = \frac{M}{(M + kS)} C_p \left[1 - e^{\frac{-(kS+M)t}{S}} \right] + C_o e^{\frac{-(kS+M)t}{S}}$$

Where:

C(t) = concentration in surface sediment at time t (mg/kg or µg/kg)

M = sedimentation rate (g/cm^2-yr)

k = combined first order rate constant for contaminant loss through decay and diffusion processes (yr^{-1})

C_p = concentration in particles being deposited on the sediment (mg/kg or µg/kg)

t = time (yr)

C_o = initial concentration in surface sediment (mg/kg or µg/kg)

The total accumulation of sediment in the mixed layer (S) is calculated as follows:

$$S = MLd(1 - p)$$

Where:

ML = thickness of mixed layer (cm)

d = density of sediment (g/cm^3)

p = porosity of sediment (cm^3/cm^3)

2.4.3.1 Marsh

SEDCAM was run for the following constituents: arsenic and mercury. The existing maximum surface sediment concentrations in the proposed marsh MNR area of these constituents were used (arsenic 1,100 mg/kg and mercury 11.9 mg/kg). Literature value sedimentation rates for 18 marshes were used. For many of the marshes, a range of sedimentation rates were reported. The lower end of the range and the upper end of the range for each marsh was used in calculating the average lower and upper sedimentation rates for all 18 marshes. The calculated lower average value (0.073 g/cm^2-yr) and upper average value (0.63 g/cm^2-yr) were used in the SEDCAM model. The value for k was set to zero because metals were modeled. There is no degradation of metals. This value is conservative because it does not account for diffusion, which the k term in the SEDCAM model accounts for. The value for S was calculated using an assumed 10 cm for the surface layer thickness, and a density assuming the marsh sediment consists of organic soil. The model was run using density and porosity assuming an organic soil (density of 0.25 g/cm^3 and a porosity of 0.8 (Brady, 1984 and Boelter, 1969)). It was assumed that the chemistry of depositing sediment post-Removal Action will be the average existing surface sediment concentration shown on Exponent's figures Horseshoe Rd/ARC OU-3 sediment Arsenic data (mg/kg) with remedial action goals and Horseshoe Rd/ARC OU-3 sediment Mercury data (mg/kg) with remedial action goals, excluding sediment in the excavation or cap area. The average was calculated using both river and marsh data because tidally influenced marsh depositional areas typically consist of particulates carried from upstream sources and from flood tide sources.

The predicted concentrations at year 5 for the marsh are presented below, along with the predicted number of years to reach the remediation goals.

Marsh						
Sedimentation Rate	**Initial Arsenic Concentration (mg/kg)**	**Predicted Arsenic Concentration (mg/kg) at 5 Years**	**Predicted Number of Years to Reach Arsenic Remediation Goal**	**Initial Mercury Concentration (mg/kg)**	**Predicted Mercury Concentration (mg/kg) at 5 Years**	**Predicted Number of Years to Reach Mercury Remediation Goal**
Low (0.29 cm/year)	1,100	546	45	11.9	6.4	20
High (2.5 cm/year)	1,100	33	5	11.9	1.2	5

2.4.3.2 River

SEDCAM was run for the following constituents: arsenic and mercury. The existing maximum surface sediment concentrations in the proposed river MNR area of these constituents were used (arsenic 171 mg/kg and mercury 2.2 mg/kg). Literature value sedimentation rates for the lower Raritan River were used. The sedimentation rate ranged from 0.28 to 1.5 g/cm^2-yr. The value for k was set to zero because metals were modeled. There is no degradation of metals. This value is conservative because it does not account for diffusion, which the k term in the SEDCAM model accounts for. The value for S was calculated using an assumed 10 cm for the surface layer thickness, and a density assuming the sediment consists of mineral soil. The model was run using density and porosity assuming a mineral soil (density of 1.1 g/cm^3 and a porosity of 0.6 (Brady, 1984)). It was assumed that the chemistry of depositing sediment post-Removal Action will be the average existing surface sediment concentration shown on Exponent's figures Horseshoe Rd/ARC OU-3 sediment Arsenic data (mg/kg) with remedial action goals and Horseshoe Rd/ARC OU-3 sediment Mercury data (mg/kg) with remedial action goals, excluding sediment in the excavation or cap area. The average was calculated using both river and marsh data because literature indicates the source of depositing material is from upstream and ocean sources.

The predicted concentrations at year 5 for the river are presented below, along with the predicted number of years to reach the remediation goals.

River						
Sedimentation Rate	**Initial Arsenic Concentration (mg/kg)**	**Predicted Arsenic Concentration (mg/kg) at 5 Years**	**Predicted Number of Years to Reach Arsenic Remediation Goal**	**Initial Mercury Concentration (mg/kg)**	**Predicted Mercury Concentration (mg/kg) at 5 years**	**Predicted Number of Years to Reach Mercury Remediation Goal**
Low (0.15 cm/year)	171	133	65	2.2	1.9	5
High (0.8 cm/year)	171	56	12	2.2	1.4	4

The predicted surface sediment concentrations for the marsh and river are based on limited site-specific data. These predicted concentrations are estimates and may not represent actual future surface sediment concentrations.

3 Capping

3.1 Introduction

The remedial alternatives proposed for OU-3 that include capping as the remedy or part of the remedy are R3, R4, and R6 (Exponent, 2007). Capping is a generic term for the in-situ containment of contaminated sediment. Contaminated sediments are covered (capped) by an appropriate material that isolates the contaminants from the water body and from ecological and human receptors.

Capping involves the placement of a natural material such as sand or gravel or a synthetic material on top of the contaminated sediment, thereby isolating chemicals from the overlying water. A cap design can be even more complex and include multiple layers of other permeable and impermeable elements combined with material to attenuate the flux of contaminants. A cap will therefore prevent receptors from having direct contact with chemicals in the sediment, as well as prevent or substantially decrease the rate of flux of chemicals from the underlying sediments. In addition, a cap will prevent resuspension and downstream migration of chemicals adsorbed onto suspended sediment.

Generally, caps are designed to fulfill three primary functions: physical isolation, stabilization/erosion protection, and chemical isolation. The thickness of a cap is determined using the following criteria (USEPA, 1998):

- limitation of chemical flux, sediment resuspension, and downstream migration of sediment
- effective isolation of chemicals from burrowing benthic organisms
- long-term serviceability of the cap, i.e., its ability to resist gravity and seismic loads; erosion caused by floods, waves, tides, currents, and incidental vessel-induced turbulence (“propeller wash”)
- other adverse events such as vessel grounding or ice damage

Sediment caps normally require a long-term maintenance and monitoring program, partly to verify that the cap has reduced the mobility of the chemicals and partly to ensure that the cap material is not eroding. Regular bathymetric surveys or diver inspections are normally conducted to verify that the thickness of the cap remains unchanged. Monitoring normally consists of periodic sampling of the cap sediment, as well as biota in the vicinity of the cap, to ensure that chemicals under the cap remain contained.

While all three potential remedy approaches (removal, capping, and MNR) should be considered at every site where they might be appropriate, some site conditions are especially conducive to capping. The following is a list of site conditions that may favor the use of a cap (USEPA, 2005):

- Suitable types and quantities of cap materials are readily available.
- Anticipated infrastructure needs (e.g., piers, pilings, buried cables) are compatible with cap.
- Water depth is adequate to accommodate cap with anticipated uses (e.g., navigation, flood control).
- Incidence of cap-disrupting human behavior, such as large boat anchoring, is low or controllable.

- Long-term risk reduction outweighs habitat disruption, and/or habitat improvements are provided by the cap.

- Hydrodynamic conditions (e.g., floods, ice scour) are not likely to create unacceptable contaminant releases.

- Sediment has sufficient strength to support cap (e.g., higher density/lower water content, depending on placement method).

- Contaminants have low rates of flux through cap.

- Contamination covers contiguous areas (e.g., to simplify capping).

3.2 Capping Technology Types

Sediment capping is considered a well-developed and mature technology. Numerous design issues and challenges are associated with caps, but ample examples and engineering guidance are available to address these design issues. Capping has been successfully used at numerous contaminated sediment sites. A recent survey conducted by Louisiana State University includes more than 100 contaminated sediment sites that were remediated using capping (http://www.hsrc-ssw.org/cap-primer.html). A number of contaminated sediment sites have included the use of capping. Tables 2 and 3 provide summaries of completed and pending capping projects.

Further information and design guidance for sediment caps can be found in USEPA, 1998. In addition, a description of capping and examples of its implementation can be accessed at http://www.epa.gov/grtlakes/ sediment/iscmain/one.html - Capping.

Capping contaminated sediments at OU-3 would require selecting an appropriate capping material, conducting site-specific slope stability analyses, and developing appropriate design and construction procedures. Special consideration needs to be given to the protection of the toe of the cap, where the forces associated with the river currents or propeller scour are the most potentially damaging to the integrity of the cap. Toe protection often involves materials or structures that are designed to resist erosion and wave forces and/or to provide lateral confinement of contaminated sediment under the cap. As an example, the toe protection could consist of rock berms that could serve both as protection for the edges of the cap and as fish habitat.

The most common types of caps are constructed of sand and/or gravel, but synthetic materials are also used. Descriptions of these types of caps are provided in Sections 3.2.1 and 3.2.2.

3.2.1 Description of Sand or Gravel Caps and Placement Method

Caps are most easily constructed using only one type of material, such as sand or gravel. The particle size is selected to maximize limitation to chemical flux from the sediment and resistance to burrowing animals, as well as to provide maximum serviceability. The cap material can be placed in one of several ways, including:

Clamshell Placement Releasing Material in Proximity of the River Bottom. The material is placed with a relatively high level of accuracy (both vertically and horizontally) and with relatively little impact to water quality in terms of resuspension of sediment or release of the cap material. This method has a relatively low production rate.

Clamshell Placement Releasing Material at or Below the Water Surface. The material is placed at a higher production rate than is the case with placement near the river bottom; however, the accuracy of the placement is not as great. The potential impact to water quality is greater than with placement near the river bottom.

Clamshell cap placement.

Barge Dumping Placement. Relatively large amounts of cap material can be placed with bottom-dump barges, which may open across the hull or have hatches that open to release the cap material. Either method allows a high production rate. Relatively accurate placement of the material can be achieved by sequencing the opening of the barge hatches. Water quality impacts are similar to those associated with clamshell placement of cap material.

Barge dump cap placement.

Tremie Piping/Pumping Placement. The cap material is typically piped in a slurry form directly onto the river bottom. This placement technique provides good accuracy and relatively low impact to water quality. This method is best for the placement of fine-grained cap material.

Sand Wash Technology. The cap material is placed on the deck of a barge over the intended area of placement and washed overboard. This method is suitable for very soft or unstable river bottoms where clamshell placement may cause resuspension or release of contamination. The water quality impact is greater with this technique, because the cap material travels across the entire water column to reach its target area.

Conveyor Placement. Articulated conveyors can be used to place capping material. Intermediate accuracy can be achieved with this method, but results are generally dependent on operator skill. The impact on water quality may be relatively high because the material is dumped above the water. This method may be suitable for placement of capping material under pier structures.

Articulated conveyor cap placement.

3.2.2 Description of Synthetic Caps

Synthetic caps may be constructed of synthetic liners, self-hardening aggregate, concrete-filled fabric mattresses, and absorbent layers, as discussed below.

Synthetic Liners. Synthetic liners have been used extensively in environmental restoration projects, but their inclusion in Superfund sediment caps has been relatively limited.

Cap construction using synthetic materials.

Self-Hardening Aggregate. Self-hardening aggregate capping material uses a proprietary blend of clay minerals, polymers, and other additives around an aggregate core. After installation, the mixture hydrates and forms a continuous low-permeability barrier that also resists erosion. AquaBlok™, one type of self-hardening aggregate that has been proposed for use in OU-3, has been used for this application in a demonstration project on the Ottowa River near Toledo, Ohio. According to the manufacturer, results of that capping project were favorable in that the AquaBlok™ remained in place, did not erode, and little mixing occurred at the sediment-AquaBlok™ interface. However, the project does not yet provide information on the performance of AquaBlok™ over the long term.

Concrete-Filled Fabric Mattresses. Concrete mattresses, such as FabriForm™ (http://www.fabriform1.com/), typically consist of two layers of non-woven geotextile stitched together and filled with a cement-based grout. The thickness of the barrier is 4 to 8 inches. The installation involves floating the geotextile mattress in place, sinking it to the bottom, and then filling the mattress with a cement-based grout. A layer of habitat substrate (a manufactured gravel/sand mix that provides suitable habitat for the recolonization of benthic communities) may be placed on the mattress to expedite reestablishment of a benthic community.

Absorbent Caps. Absorbent caps typically consist of two layers of non-woven geotextile stitched together and filled with organoclay. Organoclay materials are usually a proprietary blend of montmorillonite or hectorite clay and various polymer additives. These clay minerals exhibit high capacity for absorbing liquid-phase contamination. Absorbent layers in caps are normally used to capture chemicals that might be driven through the cap by an upward groundwater gradient and especially to capture nonaqueous-phase liquid (NAPL) seeps.

3.3 Evaluating Capping as a Remedy

The evaluation of capping technologies for use as a remedial alternative consists of three steps:

- Identification of the main types of capping technologies based on a review of existing sediment capping projects.

- Screening the capping technologies for their effectiveness and implementability with respect to site conditions (physical environment, sediment characteristics, waterway uses and infrastructure, habitat alterations).

- Evaluate whether any of the capping technologies are suitable for inclusion in the development of remedial action alternatives.

3.4 Potential Advantages and Disadvantages

The two main advantages of capping are that it quickly reduces exposure to COPCs and, unlike dredging or excavation, it requires less infrastructure in terms of material handling, dewatering, treatment, and disposal. Compared to dredging, a well-placed cap that is well-designed will quickly reduce the exposure of fish and other biota to contaminated sediment, because there is no (or very little) contaminant residual on the surface of the cap. The cap can also potentially enhance or improve the habitat substrate by providing a clean surface for recolonization by bottom-dwelling organisms or by creating more desirable habitat for higher trophic species. Typically, the risks associated with dispersion and volatilization of COPCs during construction and the potential for resuspension is lower for capping than for dredging operations. Additionally, the risks associated with transportation and disposal of contaminated sediment are avoided (USEPA, 2005).

The main disadvantage of capping is the contaminated sediment remains in place. If the cap is significantly disturbed, contaminants could become exposed or dispersed. This could also happen if the contaminants move through the cap in significant amounts. In some environments, it may also be difficult to place a cap without significant contaminant losses from disruption or compaction of the underlying sediment. Shallow water bodies, like the Raritan River near OU-3, may require institutional controls to protect the cap from man-made disturbances such as boat anchoring (USEPA, 2005).

In some situations, another disadvantage may be that a preferred habitat is not provided by the cap materials. Coarse cap materials may be a design requirement to provide erosion protection, but the use of those materials may alter the biological community used to native soft bottom materials. However, some situations may require the capping materials to discourage native deep-borrowing organisms to limit bioturbation (USEPA, 2005).

4 Dredging

4.1 Introduction

The remedial alternatives proposed for OU-3 that include dredging as the remedy or part of the remedy are as follows: R3, R4, R5, and R6 (Exponent, 2007). The most common means of removing contaminated sediment from a water body is dredging. The use of dredging also necessitates transporting the sediments for treatment and/or disposal and frequently this method involves treatment of the water from the dewatered sediments prior to discharge. The U.S. Army Corps of Engineers (USACE) dredges sediment at numerous locations on a routine basis for the maintenance of navigational channels. Navigational dredging maintains the waterways for recreational, commercial, and national defense purposes, and is usually conducted in the most efficient and economical manner. Environmental dredging is performed specifically to remove contaminated sediment above certain action levels while minimizing the spread of contaminants during dredging. Due to the specialized circumstances to meet cleanup objectives, environmental dredging can be inefficient and costly.

Components that must be evaluated when considering dredging as a cleanup method include debris removal, sediment removal, transport, staging, treatment (pre-treatment, potential treatment of both water and sediment), and disposal (liquids and solids). Not all components would be necessary, depending on the site and scope of the project (USEPA, 2005).

The following sections summarize the dredging technologies and technologies that would be used subsequent to and in conjunction with dredging, which include transport, treatment, and disposal technologies. A full discussion of treatment methods has not been included as treatment was screened out of the remedial technologies retained for potential use at OU-3.

4.1.1 Dredging Technology Types

The type of dredging technology selected is often based on the purpose of the dredging and the site conditions, including the volume of sediment to be removed, physical characteristics (water depth, waterway widths, steepness of slopes), and in-water and upland operations. Technologies primarily used for navigational dredging (i.e., hydraulic types such as hopper and dustpan dredges, and mechanical types such as bucket-ladder and drag-line dredges) have been eliminated from this discussion because of the lack of vertical and horizontal accuracy required for environmental dredging applications and the lack of effective resuspension control.

The following technologies are generally considered suitable for environmental dredging projects (Palermo et al., 2004; Herbich, 2000):

1. Mechanical
    a. Open clamshell bucket
    b. Level cut clamshell bucket – cable crane operated
    c. Barge-mounted excavator with conventional bucket
    d. Barge-mounted excavator with bucket-closing mechanism

2. Hydraulic
    a. Plain suction
    b. Cutterhead dredge
    c. Horizontal auger

3. Pneumatic
    a. Oozer pump
    b. Pneuma pump

4. Specialized
    a. Toyo pump
    b. Eddy pump

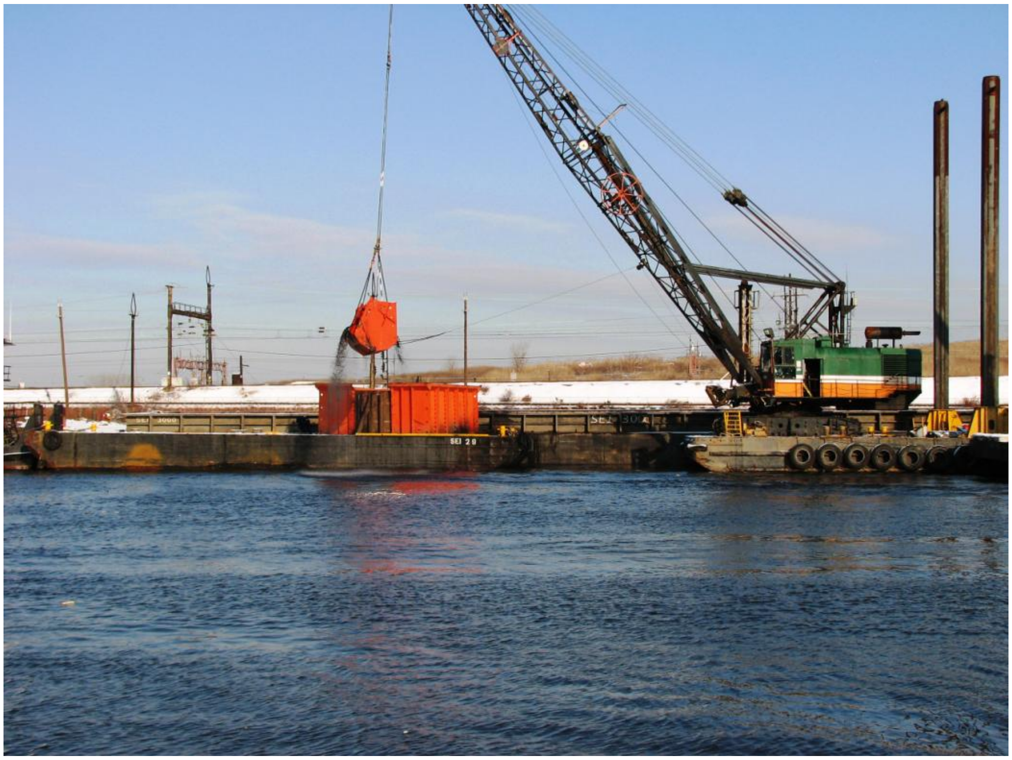
Descriptions of these dredging technologies are provided below and are summarized in Table 4.

Mechanical Dredges

Open Clamshell Bucket. The open clamshell bucket is typically operated via the wires of a conventional cable arm crane. The crane can operate from land or it can be barge-mounted. The clamshell bucket is lowered to the mudline and penetrates the sediment in the open position by gravity impact. Sediment is trapped in the clamshell bucket by closing the bucket using the crane's wires. The sediment can then be lifted to the surface and out of the water, where it is typically placed on a barge for transport to shore. Different bucket types and sizes are available. Buckets of up to about 60 cubic yards (cy) are available regionally, but sizing of 5 to 20 cy would be more applicable to environmental dredging. Particularly on slopes, a smaller bucket should be used to avoid excessive overdredging and sediment instability. Some buckets make circular-shaped cuts; newer buckets are capable of making level cuts, leaving a relatively flat surface. Level-cut buckets should be used when possible to increase dredge accuracy, avoid large amounts of overdredging, and reduce sediment resuspension. In addition, sediment resuspension is further reduced by using level-cut buckets to dredge unconsolidated soft sediments. However, lightweight level-cut buckets are unsuitable for digging in harder consolidated sediments.

Dredging using an open clamshell bucket.

Level Cut Clamshell Bucket. This technology uses a modification of the conventional clamshell bucket described above. While the bucket is also operated by a cable arm crane, the clamshell is modified such that the bucket is nearly watertight or sealed in the closed position. This reduces sediment resuspension, particularly in the upper water column. Recent designs also incorporate the capability of making level cuts as opposed to the circular-shaped cuts made by conventional buckets. As with the open clamshell bucket technology, level-cut buckets should be used when possible to increase accuracy, minimize the need for overdredging, and further reduce sediment resuspension.



Dredging using a level cut clamshell bucket.

Barge-Mounted Excavator with Conventional Bucket. Excavators with conventional digging buckets can be mounted on a barge for dredging operations. Instrumented buckets have been used for greater dredging accuracy (e.g., the Bonacavor by Bean Stuyvesant, LLC). However, the availability of instrumented excavators is likely very limited; such equipment might have to be mobilized from as far away as Louisiana. Less highly specialized excavators with conventional buckets are usually available. The maximum dredge depth is about 25 feet unless a specialty long-reach backhoe is used. Land-based excavators could be used for slope cuts, if required, although this would typically require an even larger excavator arm due to dock or bank height.

Dredging using a barge-mounted excavator.

Barge-Mounted Excavator with Bucket-Closing Mechanism. The setup for this equipment is generally the same as for the conventional barge-mounted excavator, with the exception that the bucket attached to the excavator is modified to include a closing mechanism that reduces the amount of sediment washed out of the bucket.

Hydraulic Dredges

Hydraulic Cutterhead Dredges. A number of dredges use a combination of mechanical cutting action and hydraulic suction created by pumps to excavate sediments. Hydraulic cutterhead dredges are typically available as barge-mounted units, although dredging depth is typically limited to 40 feet or less because these units are smaller than other types of dredges. The main components of these dredges are a dredge head, which cuts the material to be dredged, and a submersible centrifugal pump, which creates suction to pick up the material. The dredge head is typically mounted on a moving support system (referred to as a ladder) that also supports a suction line. The suction line transports the material to the main pump and on to the discharge pipe. Dredges with different dredge heads are available. The most commonly available type is the cutterhead dredge, which uses a rotating cutting device to dislodge sediments. Another hydraulic cutterhead dredge type available is the horizontal auger dredge, commonly referred to as the Mud Cat™ (Baltimore Dredges LLC). Other dredges with specialty dredge heads include the Boskalis Environmental Disc Cutter, the Slope Cleaner, Clean Sweep, Water Refresher, Clean Up, and Swan 21 systems (Palermo et al., 2004). These dredges are not as widely available as the cutterhead and horizontal auger dredges. Specialty dredge heads are available equipped with design features such as mud shields to reduce sediment resuspension.

Plain Suction Hydraulic Dredges. Dredges that use only hydraulic action and no cutting action to excavate sediments are commonly referred to as plain suction dredges. Several designs with different dredge heads are available, including cutterhead dredge with no cutter basket mounted, Matchbox dredge head, articulated Slope Cleaner, Scoop-Dredge BRABO, and others (Palermo et al., 2004). Many of these designs incorporate dredge heads with special design features such as flexible enclosures or special suction heads to reduce sediment resuspension. Smaller-size dredge heads can be used for diver-assisted dredging.

Pneumatic Dredges

Several types of pneumatic dredges have been used in the cleanup of contaminated sediments. The more common pneumatic dredge types are described below.

Oozer Pump. The Oozer pump is an air-operated submersible pump that is typically mounted at the end of a ladder. Suction is created by use of hydrostatic pressure and additional creation of a vacuum to pick up the sediment and fill two cylinders. The pump is typically equipped with special high-frequency acoustic sensors that measure the sediment thickness being dredged, the bottom elevation after dredging, and the amount of resuspension. Additionally, cameras can provide the operator with visual information.

Pneuma Pump. The Pneuma pump creates pneumatic force to suck sediments into three cylinders. Compressed air is then used to force the sediment out of the cylinders and into the discharge pipeline. The pump can be suspended from a barge-mounted crane or mounted at the end of a ladder similar to a cutterhead dredge. Dredging results are typically better when the pump is mounted to a ladder.

Specialized Dredge Technologies

Toyo Submersible Agitator Pump. The Toyo system typically consists of a submersible agitator pump that is attached to a flexible pipe and suspended from a barge-mounted (typically 30- to 50-ton) crane. Mobilization of the pump itself is relatively easy and can be accomplished by truck. The built-in agitator consists of rotating cutter blades and is located at the intake end of the pump. The system can be equipped with a global positioning system mounted on the crane and depth sensors to provide information on the location of the pump during dredging. A magnetic flow meter/density meter can provide solids content and production measurement. The manufacturer claims that the pump is capable of moving material at up to 70 percent solids by weight and of picking up rock of 5-inch size or less. Production rates range from about 30 to 60 cy/hour for the DP-30 model to about 150 to more than 300 cy/hr for the DP-150-B model. Production rates would likely be lower if debris larger than 5 inches is present.

Eddy Pump. The Eddy pump is a submersible pump that creates a dynamic fluid eddy effect within the pump housing and inlet to pick up sediments. The manufacturer compares this mechanism to a tornado or vortex that picks up objects from the ground. The eddy effect is created by a rotor within the pump that is located above the intake. The pump is attached to a flexible pipeline and can be suspended from a barge-mounted crane or ladder. By virtue of the negative pressure caused by the vortex in the pump, the system is essentially leak-proof. The Eddy pump system used for environmental dredging is designed for easy transportation and with a unique spud system that allows great maneuverability. Pumps of various sizes (4-inch, 6-inch, 8-inch, and 14-inch) are available. On various demonstration projects, this pump dredged material at solids contents of 55 percent to 90 percent by weight at rates of 187 to 200 cy/hour and was used in widely varied bathymetric, environmental, and climatic conditions.

4.1.2 Evaluating Dredging Technologies

Dredging technologies are typically evaluated as a potential remedy with regard to the following factors:

Sediment Resuspension. The effectiveness of each technology is evaluated in terms of sediment resuspension. The resuspension characteristics of a dredging technology determine how well the contractor can meet the requirements of water quality standards. If water quality standards cannot be met during construction, the contractor may have to change procedures or switch to a different technology, which could result in delays and additional costs. Poor sediment resuspension characteristics could also result in reduced production rates, slowed construction, and the spread of contaminants.

Availability. Availability of a technology can determine its feasibility. Even when technologies are generally available, mobilization may be costly because the equipment is distant from the site. However, other characteristics may make a technology with limited availability desirable and cost-effective for specific conditions.

Site Compatibility/Technical Feasibility. To be technically feasible, a technology needs to be compatible with the characteristics of the site, including sediment volumes to be dredged, water depths, channel widths, and the presence of structures, obstructions, and debris. The compatibility of a dredging technology with subsequent technologies is a separate question.

Solids Content. The solids content of the dredged material affects subsequent technologies, including transport, treatment, and disposal. If large amounts of water are added to the sediments during dredging, the solids content decreases. For offsite disposal options that include transport by truck, rail, and barge, as well as for treatment, it is generally beneficial if the sediments can be dredged near the in-situ solids content (i.e., without additional water).

Production Rate. The dredging production rate affects the construction schedule and costs. Production rates often vary widely among dredging technologies and depend heavily on site conditions such as the presence of debris, obstructions, and structures, as well as water depths. Frequently, manufacturers' stated production rates are based on experience with dredging that is not performed for environmental purposes. However, dredging may have to be performed at slower rates when contaminated sediments are being dredged to accomplish specific environmental objectives, such as minimizing the amount of sediment resuspension; the extent to which resuspension is reduced by slower production rates depends on the dredging technology, as well as on the transportation and disposal technologies selected. At OU-3, the production rate will be seriously affected by the low water depth in the Raritan River at the site. During low tide the area becomes a mudflat. Dredging will likely have to coincide with the tidal schedule which will impact the schedule and decrease the production rate.

Past Performance. The performance of a technology on other, similar dredging projects can be used as an indicator of how the technology would perform at a site.

When dredging is selected as a remedial alternative, sediment resuspension is an important factor in selecting dredging technologies. The contractor will generally select a dredging technology that enables them to meet water quality standards while maintaining production rates that meet other project requirements. Compatibility of the dredging technology with subsequent technologies, including transport and disposal, is an important criterion as well. Transport and disposal are greatly affected by the solids content of the dredged material. Mechanical dredging adds the least amount of water to the sediments to be dredged and would require the least amount of dewatering or use of drying agents. Mechanical dredging is therefore a likely candidate for alternatives that involve landfill disposal, such as those proposed for OU-3. Dredging technologies other than mechanical dredging will likely add a relatively large amount of water to the sediment and will decrease its solids content. Sediments dredged using hydraulic cutterhead, hydraulic, pneumatic, or specialty dredges and pumps are typically suitable for pipeline transport, but would likely require a fair amount of dewatering in conjunction with other transport technologies.

4.2 Transport

4.2.1 Transport Technology Types

Transport technologies will be used in conjunction with dredging and disposal. Once the sediments at OU-3 have been dredged, they will be transported to an offsite disposal facility. Processing of the dredged material may consist of dewatering or solidification, depending on the disposal technology, and these technologies are described further in Section 4.4.1.2.

Transport technologies commonly applicable to dredging projects are:

- truck transport

- rail transport
- barge transport
- pipeline transport

This section describes each of the transport technology types.

Truck Transport

Truck transport of dredged sediment is generally used in conjunction with offsite disposal at a landfill. Truck transport would require construction of an onsite transload facility where the dredged sediments could be transferred from a barge or a stockpile to the trucks. Dredged sediments most often require some level of dewatering to achieve a moisture content that will preclude water drainage from the trucks during transport. Truck transport usually works best in combination with mechanical dredging, because mechanically dredged material contains less water than hydraulically dredged material and needs less dewatering.

The dredged material would likely be placed in lined roll-off boxes or containers, because additional free water could be generated during transport as a result of vibration. Truck transport is heavily influenced by traffic, weather, and road conditions, which may affect travel time and thus turnaround time. The rate at which material is hauled offsite by truck must meet the requirements set by dredging production, i.e., the material must be hauled offsite quickly enough to avoid shutdown or delay of the on-water operations. If, based on dredging productivity, the cycle time required to fill one truck is less than 10 minutes, loading of trucks likely becomes a challenge. In addition, simply obtaining enough trucks to keep up with the dredge production rate may be difficult. Trucking can generally be used in combination with other transport technologies, if trucking alone cannot keep up with dredge production.

Rail Transport

If a site has rail access like the Horseshoe Road/ARC Superfund Sites, rail transport is a viable transport option for offsite disposal of dredged sediment at a landfill. Rail transport should generally work well in conjunction with mechanical dredging, but will work less well in conjunction with hydraulic dredging. Mechanical dredging adds significantly less water to the sediments than does hydraulic dredging. Hydraulically dredged material would likely require significant material processing, such as dewatering or solidification, prior to transport. The dredged sediment may be placed in lined railcar boxes (containers) or gondolas. Railcars comprised of buggies to carry containers have a capacity of 90 tons, while gondolas have a capacity of 105 to 115 tons. It may be necessary to construct a transload facility at the site for rail transport which would not be cost effective at OU-3.

Barge Transport

Barges can be loaded during dredging without rehandling of the dredged sediments. A tugboat may be required to move the barges. Most barges can typically carry up to 3,000 cy of material. In general, barge transport is relatively slow and the contractor would have to supply several barges to allow dredging to continue while full barges traveled to their destination. Due to the low water levels in the Raritan River at OU-3, it is unlikely that transport by barge will be viable.

Pipeline

Pipeline transport could be used in conjunction with onsite disposal in a CDF. Pipeline transport is typically not applicable to offsite disposal because of the long distance that must be traveled to reach USEPA-approved landfills. To allow pipeline transport, the material to be transported generally needs to have a fairly low solids content (i.e., the material should be a slurry) so that pumps can move the material through the pipes. Therefore, hydraulic dredging works well in conjunction with pipeline transport. Mechanical dredging can also be coupled with hydraulic transport of the dredged sediment whereby additional water is mixed with the sediment to achieve a slurry that can be pumped. Hydraulic, hydraulic cutterhead, pneumatic pump, and high-solids pump dredges are generally all compatible with pipeline transport, although it may be necessary to use booster pumps if pipeline lengths exceed limitations of the main dredge pump.

4.2.2 Evaluating Transport Technologies

The evaluation criteria against which the transport technologies are screened are described below.

Protectiveness of the Public and Construction Personnel. The use of certain transport technologies may affect the health and safety of the public or the health and safety of construction personnel. Health and safety may be affected by impacts to air quality and traffic, by increased potential for vehicular accidents, by the need to rehandle contaminated sediments, and by the potential for spills.

Technical Feasibility. Technical feasibility is evaluated based on construction and operational considerations, compatibility with site conditions, compatibility with other technologies, and demonstrated performance.

Availability. The implementability of a technology is generally heavily dependent on the availability of equipment, personnel, and services.

4.3 Treatment

Since treatment options were eliminated from consideration in the Development of Remedial Alternatives Technical Memorandum (Exponent, 2006), a discussion of treatment alternatives is not included in this document. Dewatering and stabilization are not included as treatment technologies because reducing the toxicity of contaminants is not their primary purpose. Rather, dewatering and stabilization are typical steps in many sediment treatment and disposal technologies to improve the suitability of sediment for certain kinds of handling. Dewatering and stabilization are therefore discussed separately in Section 4.4.1.2.

4.4 Disposal

4.4.1 Disposal and Materials Handling Technology Types

4.4.1.1 Disposal

Offsite disposal has been proposed for the sediments at OU-3. Any upland landfill that has received USEPA approval to accept material of the type to be dredged from the site can be used for the offsite disposal component of the remedial action alternative.

4.4.1.2 Materials Handling Technologies

Many landfill facilities have moisture content requirements that would require that the sediment be dewatered or stabilized prior to disposal, which is relevant for offsite disposal. Dewatering and stabilization technologies are described below.

Dewatering. Dredged sediment is typically dewatered using a gravity dewatering system, in which water is pushed out of the material by the material's own weight. However, if necessary, mechanical dewatering may be used to process the sediment in order to achieve a moisture content suitable for disposal at an offsite commercial landfill. The water generated would be collected, tested, and discharged according to the substantive requirements of the Clean Water Act.

Stabilization. Under certain circumstances to meet landfill requirements for moisture content, dredged material will require stabilization through the addition of a drying agent. Typical drying agents include clarifier solids, fly ash, lime, and cement. Note that while the addition of a drying agent reduces or eliminates free liquids, it also adds to the weight of the material to be disposed of.

There are certain landfills permitted to accept free liquids, which therefore present a greater flexibility with respect to the amount of dewatering and/or stabilization. However a certain amount of dewatering will unavoidably occur as part of the handling of the dredged sediment thus necessitating the introduction of technologies associated with the collection, handling, treatment and discharging of the decant water.

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Tables

Figure

TABLE 1
SUMMARY OF SITES WHERE MNR IS PART OF THE REMEDY

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Description of Remediation and MNR	Chemical Constituents to be Addressed	Source
Alaska Pulp Corporation Mill Site, Sitka, AK	Mill OU: Removal Bay OU: MNR and institutional controls.	Petroleum and dioxin	ROD, ALDEC, April 1999
Alcoa (Point Comfort)/Lavaca Bay Site Point Comfort, Texas	Groundwater and DNAPL collection and treatment, dredging of sediments, dredging or filling of marsh. Upland soils removal, capping and institutional controls. TLC in areas north of Dredge Island. Other sediment areas will recover to acceptable levels through natural sedimentation. Area and concentration information not available.	PAHs, mercury	ROD, USEPA December 2001
Charleston Boat Yard (Coos Bay), Charleston, OR	Capping and excavation of upland and intertidal sediment. MNR for subtidal sediments, consistent with current and future use of the site as an operating boat yard.	PCBs, PAHs, metals, tri-butyl tin	ROD, ORDEQ May 2001
Columbia Slough Sediment, Portland, OR	Source control and sediment removal for multiple sources that contributed to contamination in the Slough. MNR chosen for large area affected at low levels from multiple sources.	PCBs, pesticides, metals	ROD, ORDEQ July 2005
Lower Fox River and Green Bay Site (OU1 and 2) Wisconsin	OU1: Remove > 1ppm to achieve 0.19 ppm (goal = 0.25 ppm) OU2: MNR (20 miles, 240 lbs PCBs, 339,200 cy) previous removal of Deposit N so that only 10,000 cy remain above 1 ppm, some of this to be removed as part of OU3 (see below). Current SWAC = 0.61 ppm.	PCBs	ROD, WDNR and USEPA December 2002
Lower Fox River and Green Bay Site (OUs 3, 4, and 5), Wisconsin	OU3 and 4: Remove > 1ppm, including OU2 Deposit DD (9,000 cy, 68 lbs) OU5 (Green Bay): MNR and institutional controls ($39.6M)	PCBs	ROD, WDNR and USEPA June 2003
Hudson River PCBs, NY	MNR following completion of dredging.	PCBs	ROD, USEPA February 2002
Interstate Lead Company (ILCO) Superfund Site OU3 Leeds, Jefferson County, AL	OU1 and 2: Soil, sediment and groundwater OU3 (surface water, sediment and biota): MNR and recommends fish advisory.	Lead	ROD, USEPA September 1995

TABLE 1
SUMMARY OF SITES WHERE MNR IS PART OF THE REMEDY

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Description of Remediation and MNR	Chemical Constituents to be Addressed	Source
James River, Hopewell, VA	Tidal estuary, max conc = 12 ppm, Natural recovery (slow burial by natural sedimentation) successful and fishing ban lifted 1988.	Kepone – Cl pesticide	MCSS Database, R5 Status update 8/11/98,
Koppers Co., Inc., Charleston, SC	Barge canal (3.2 acres) determined to be in such a depositional area (1.2ft/yr) that "natural" capping will occur and will achieve the objectives established for the ROD specified engineered subaqueous cap. This ESD references a 2001 ESD switching from enhanced sedimentation in the Ashley R. to engineered subaqueous cap.	Pentachlorophenol, copper arsenate	ESD, USEPA, September 2003
Little Mississinewa River OU1, Union City, IN	Removal: Sediments, top 1': 4 ppm; deeper: 5ppm; residential floodplain – 5 ppm; recreational floodplain - 20ppm. To achieve clean-up goals: sediment surface: 1 ppm; deeper: 5 ppm; res FP: 1.2 ppm; and rec FP: 20 ppm. MNR in river channel that does not require excavation but has PCBs > 1ppm. MNR to include monitoring fish tissue concentrations.	PCBs	ROD, USEPA July 2004
Onondaga Lake Bottom Subsite, Syracuse, NY	SMU 1- 7: Remove 2,653,000 cy, cap SMU 8 pilot scale study/full scale implementation of oxygenation, and TLC. MNR to assess recovery with additional measures, if needed.	Mercury	ROD, NYSDEC, USEPA July 2005
Sangamo Weston/Twelvemile Creek/Lake Hartwell OU2, Pickens, SC	OU1: Removal of source areas OU2: MNR, natural capping, and fish advisories. Five-year review was done in 2004 and indicated "The MNR/Institutional Controls remedy for OU2 is considered adequately protective of human health and the	PCBs	ROD USEPA June 1994; Five-Year Review USEPA 2004

TABLE 1
SUMMARY OF SITES WHERE MNR IS PART OF THE REMEDY

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Description of Remediation and MNR	Chemical Constituents to be Addressed	Source
	environment while long-term monitoring of aquatic biota and sediments continue in the future."		
Shiawassee River OU1, Howell, MI	Excavation and dredging 3,345 cy followed by MNR.	PCBs	ROD, USEPA September 2001
Wyckoff/Eagle Harbor Superfund Site East Harbor OU, Bainbridge Island, WA	Capping in subtidal areas, ". . . monitoring in intertidal areas to confirm the predicted recovery of intertidal sediments through natural processes."	PAHs and other, free phase oily	ROD,USEPA September 1994

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
ALCOA — Grasse River, NY	Pilot Study	Pilot tested several different cap placement techniques (surface and subsurface placement via clamshell, subsurface placement via tremie pumping and surface placement via pneumatic broadcasting) and several different cap materials (1:1 sand/topsoil mixture, granulated bentonite, AquaBlok™) ranging from 3 inches to 2 feet in depth	2001	~7 acres	PCBs	• Water quality monitoring during cap placement indicated negligible effects to the water column • Monitoring performed in 2001 and 2002 indicated that the caps were intact, no evidence of PCBs moving into or through the cap and a variety of organisms were recolonizing the area. • Monitoring of the river in spring 2003 revealed that the cap, and in some areas the underlying sediment, had been disturbed as a result of ice-jam-related scour caused by a severe ice jam. This event was not expected and the caps were not designed to withstand the forces generated by such a severe event.
Anacostia River, DC	Pilot tests, river	4 inches of AquaBlok™, 6 inches of sand	2004	80 feet by 100 feet	PAHs, PCBs and metals	• Sediment cores, water sampling, physical monitoring, seepage meters and piezometers.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Anacostia River, DC (continued)	Pilot tests, river (continued)	12 inches of sand	2004	80 feet by 100 feet	PAHs, PCBs and metals	• Sediment cores, water sampling, physical monitoring, seepage meters and piezometers.
		Apatite "active cap," precipitation and sorption of metals, 6 inches of apatite, 6 inches of sand	2004	80 feet by 100 feet	PAHs, PCBs and metals	• Sediment cores, water sampling, physical monitoring, seepage meters and piezometers.
		Coke breeze "active cap" absorbs hydrophobic organic contaminants, 6 inches of coke breeze, 6 inches of sand	2004	80 feet by 100 feet	PAHs, PCBs and metals	• Sediment cores, water sampling, physical monitoring, seepage meters and piezometers.
Bayou Bonfouca Superfund Site, LA	"Channel fill"	Sand/gravel layers	1995	Unknown	PAHs	• Unknown.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Central Long Island Sound Disposal Site, NY	CAD — seven mounds in open water	Varied: mean 8 to 16 inches silt and/or sand	1979-1994	Large	Oil, grease, heavy metals and PCBs	• 15 years of monitoring, including physical, chemical and biological tests. Surface samples and cores. • Normal recolonization, surficial sediments clean, poor recolonization where caps not placed correctly.
Cherry Farm/River Road Site, Tonowanda, NY	River capping, state-led project	Riprap and geotextile	July 1999	~ 0.5 acres	PCBs, PAHs and metals	• Unknown.
Collins Cove, Salem, MA	Tidal flat capping (dual purpose)	Varied: geosynthetics with armor on the toe and geoweb with armor on the higher elevations	2007	~ 4 acres	NAPL	• Unknown.
Commence ment Bay Superfund Site — Asarco Tacoma Smelter, WA	Subtidal shoreline capping (pilot cap complete)	3 feet of sand with gravel armor	2003	18 acres	Arsenic and metals	• Unknown.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Commencement Bay Superfund Site — Hylebos, Waterway, WA	Embayment/ nearshore capping, USEPA lead	2 to 20 feet clean sand and gravel (backfill)	2003	1.5 acres	Arsenic, PCBs, PAHs and hexachloro-benzene	• Physical integrity monitoring (diver survey). • Good condition.
Commencement Bay Superfund Site — Middle Waterway, WA	Embayment/ nearshore capping, USEPA lead	45 cm clean silty sand topped with cobble/gravel and fine-grain sand	2004	2.15 to 6.5 acres	Mercury, copper and PAHs	• Physical integrity and sediment sampling. • Positive results.
Commencement Bay Superfund Site — Olympic View Resource Area, WA	Nearshore capping, USEPA lead	Minimum 3 feet of clean material	2003	1 acre	Dioxins, metals, PCBs and PAHs	• Conventional and bathymetric surveys and visual inspections indicated minor erosion the first year, but less the second year. Surface sediment sampling showed that constituents were not migrating through the cap.
Commencement Bay Superfund Site — St. Paul Waterway, WA	Nearshore capping, USEPA lead	4 to 20 feet of Puyallup River sediments	1988	17 acres	VOCs, SVOCs, PAHs and organic debris	• Bathymetric surveys, visual inspections, aerial photographs, surface and subsurface sediment sampling, seep sampling and biological sampling. • Fifteen years of monitoring indicated no contaminant migration, minimal erosion and healthy habitat recolonization.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Commencement Bay Superfund Site — Thea Foss Waterway, WA	Embayment/ nearshore capping, USEPA lead	Multilayer: thick sand, sorbent and geotextile, or 3 feet of sand	2004	Between 8-20 acres each	PAHs, PCBs, metals and NAPL	• Surface sediment sampling and visual inspections. • Some top-down recontamination from nearby stormwater discharge source. • Minor erosion at northeast end of one cap, but coarser materials are settling in the area ("self-armoring").
Commencement Bay Superfund Site — Wheeler-Osgood Waterway, WA	Embayment/ nearshore capping, USEPA lead	Minimum 3 feet Puyallup River sediments.	2004	<13 acres	PAHs, PCBs and metals	• Sediment sampling and visual inspections. • Some top-down recontamination from nearby stormwater discharge source.
Convair Lagoon, CA	Embayment capping	Geogrid, 1 foot gravel, 2 feet sand	1998	5.7 acres	PCBs	• Periodic visual inspection by divers, cap thickness, sediment cores. • Some scour noted as a result of high velocities (up to 40 fps). As of 2003, cap is functioning as designed. However, elevated concentrations of PCBs have been found in sediment on the surface of the sand cap.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Crotty Street Channel, MI	Channel capping	Grading layer, 6 inches sand, HDPE liner, geonet, filter fabric, 12 inches soil, 6 inches topsoil	2000	2.3 acres	PCBs	• Unknown.
Denny Way CSO, Seattle, WA	Nearshore capping	2-3 feet sand	1990	3 acres	Lead, mercury, zinc, PAHs and PCBs	• Physical, chemical and biological tests; surface samples and cores; use of SPVC; diver inspections. • No chemical migration into cap, some top-down recontamination from ongoing source, no erosion noted during inspections.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Duwamish/ Diagonal CSO/SD, WA	CAD	Minimum of 3 feet of armoring materials (including base capping sand, sandy-gravel, quarry spalls and riprap)	2004	7 acres	Bis(2-ethylhexyl) phthalate (BEHP) and PCBs	• Physical, chemical, surface samples and cores to be collected each year during the first 5 years after cap completion. The frequency of sampling events during the next 5 years would be determined based on the rate of recontamination observed during the first 5 years of monitoring. If recontamination appears to have stabilized after 5 years, then monitoring could be reduced to alternating years.
		Thin layer of sand was placed around the dredged area to reduce the level of contaminants from previous dredging activity.	February 2005			

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Duwamish River, Seattle, WA	CAD for 1,100 cy of dredged material	1-3 feet sand (2 feet average)	1984	4 acres	Metals, PCBs, phthalates and pesticides	• Chemistry from vibracore. No chemical migration observed during second and third sampling events; erosion covered by sedimentation. • First sampling event indicated lens of contaminated sediment in cap (possibly from placement).
Eagle River Flats (OU #3), Fort Richardson Superfund Site, Alaska	Pilot study	1 to 1.5 feet pit-run gravel over geofabric layer	2007	Small pond (<5m wide by 1m deep)	White phosphorus	• Waterfowl health, physical robustness and settling effectiveness. • Deferred until ice melts.
Estriheim Bay, Norway	Bay capping	Geotextile and gabions	Unknown	25 acres	Metals	• Unknown.
Hamilton Harbour/ Randle Reef, Ontario	Harbor capping — demonstration project	1.6–foot sand layer	1995	2.5 acres	PAHs and metals	• Bathymetry, turbidity, visual observation, sediment cores, porewater and consolidation. • Short-term monitoring indicates minimal consolidation and a sharp sediment/cap interface.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Harbor Island Superfund Site — Lockheed Shipyard, Seattle, WA	Nearshore capping (federal lead)	2 feet sand	2005	4.4 acres	Metals, PCBs, PAHs, TPH, methane, ferrous Fe, CO_2, DO, alkalinity, sulfate trichloro-ethylene and tetrachloro-ethylene	• Visual inspection and cap sampling. • Results not yet reported.
Harbor Island Superfund Site — Todd Shipyard, Seattle, WA	Nearshore capping (federal lead)	2 feet sand	2005	~2 acres	Metals, PCBs, PAHs, TPH, methane, ferrous Fe, CO_2, DO, alkalinity, sulfate trichloro-ethylene and tetrachloro-ethylene	• Visual inspection, turbidity and water quality monitoring. • Results not yet reported

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Ketchican Pulp Company Superfund Site — Ward Cove, AK	Deep water capping	6-12 inches sand	2001	27 acres	Ammonia, sulfide, 4-methylpehnol, metals and organic compounds	• Bioassay, bulk sediment and benthic community analysis.
Koppers (Charleston Plant) Superfund Site, SC	River capping, USEPA lead	At least 1 foot of sand underlain by a geotextile	December 2001	~ 2 acres	PAHs, dioxins and metals	• Settlement and thickness monitors have been placed in a regular grid to measure cap integrity through time. • Five-year report has not yet been released.
		2 feet of stabilized and solidified sediment		~ 1 acre		
Kure Bay, Japan	Embayment capping (two phases)	1.5 feet and 1 foot of sand	1979/1980	16 acres	Industrial chemicals	• Chemistry and biological tests, rapid recolonization.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Lake Biwa, Japan	Experimental: 8 inches of sediment dredged, then capped	0.7 foot of sand	1992	6 acres	Unknown	• Unknown.
Manistique Harbor (Area B)	River capping	Gravel	1998	<0.5 acre	PCBs	• Unknown.
Matsushima Bay, Japan	Experimental: sediment dredged, then capped	1 foot of sand	1993	4.7 acres	Unknown	• Unknown.
McCormick & Baxter Superfund, OR	Embayment/ nearshore capping, ODEQ lead	2-5 feet sand, organoclay, articulating concrete block mats, riprap, geotextile fabric and rocks	2005	22 acres	Heavy metals, PAHs, dioxins and PCP	• Visual inspection, aerial photographs, bathymetry, sonar, diver inspection, water, pore water, flux chamber and organoclay cores. • Minor erosion of cap armoring and NAPL sheens have been observed in discrete locations. • Areas covered with organoclay mats and heavy armoring.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
McCormick & Baxter Superfund, OR (cont'd)	Embayment/ nearshore capping, ODEQ lead	2-5 feet sand, organoclay, articulating concrete block mats, riprap, geotextile fabric and rocks	2005	22 acres	Heavy metals, PAHs, dioxins and PCP	• In 2010, ODEQ will determine whether remedies are meeting the remedial action objectives with extensive monitoring.
Minamata Bay, Japan	Embayment capping	2.5-foot sand cap with geotextile	1988	80 acres	Mercury	• Unknown.
Montrose Chemical Co. Superfund Site — Palos Verdes Shelf, CA	Pilot project (three deep water pilot capping sites)	Different thicknesses of sand varying from 6-18 inches	2000	135 acres (45 acres per cell)	DDT and PCBs	• Placement technique, stability, effectiveness of material type, impacts and ocean fish monitoring. Studies showed low potential for cap disruption. • Results of geotechnical studies are pending additional investigation.
New Bedford Harbor Superfund Site, MA	Pilot study south of Hurricane Barrier	Up to 5 feet sand/CAD	2005	~ 19 acres	PCBs	• Physical, chemical and biological quality monitoring annually. • No monitoring results available yet.
New York Bight, NY	CAD — mound in 80 to 90 feet of water	Average 3-4 feet of fine sand	1980	Large	Various	• Physical, chemical and biological tests. Surface samples and cores. • No significant erosion or migration of contaminants.
Norfolk	Nearshore	3-9 feet clean sand	1999	~2 acres	PCBs and	• Sediment sampling and surveys.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
CSO, WA	capping (WA Department of Ecology lead)	(backfill)			mercury	• Some recontamination from ongoing source (contaminated sediment removed and source fixed), cap in good condition, surficial sediment sampling indicated no chemical migration into cap.
North Energy Island Borrow Pit, CA	Pilot Study, disposal area, Los Angeles Harbor, USACE lead	47 inches of sediment	2001	305 meters by 1,525 meters (115 acres)	PAHs and metals	• Bathymetry, sediment cores, video transects, benthic samples and pore water. • Successful.
One Tree Island Marina, Olympia, WA	CAD for 3,900 cy of dredged material	4 feet sand	1987	0.4 acre	Metals and PAHs	• Physical, chemical and biological tests. Surface samples and cores. • Surficial sampling indicated no chemical migration into cap, no erosion noted in visual observations.
Ottawa River, OH	Three pilot sites	0.5-0.67 foot AquaBlok™ (clay-based), geotextile, stone armor	1999	2.5 acres	PCBs	• Benthos, elevation survey and sediment cores. • Sharp boundary exists at cap/ sediment interface.
Oxbow Lake, WI	Oxbow lake adjacent to the Rib River	Geotextile, sand blanket, second layer of geotextile and rock “islands”	February 1997	4 acres	Lead	• Water column monitoring in March 1999 showed no impacted sediment or sediment interstitial water is migrating through the cap. Annual inspections of the cap’s physical integrity and periodic testing of the

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
						pore water were scheduled.
Pacific Sound Resources Superfund Site, WA	Bay capping, Elliott Bay, USEPA lead	5 feet sand, gravel and broken rock	February 2005	58 acres	PAHs and heavy metals	• Groundwater sampling, and DNAPL and groundwater volume trends. • Minor concentrations of PAHs, PCBs and PCP, no NAPL migration.
Pier 51, Seattle, WA	Nearshore capping	1.5 feet coarse sand	1989	4 acres	PAHs, PCBs, PCDFs and metals	• Sediment samples and diver surveys. • No chemical migration, recontamination of surface from off-site sources, no erosion or recolonization observed.
Pier 53-55, Seattle, WA	Nearshore capping	1.3-2.6 feet sand	1992	4.5 acres	Metals, PAHs and PCBs	• Subsurface chemistry, surface chemistry, benthos and sediment profile camera. • Surface recontamination from off-site sources, no chemical migration, minor erosion, cap stable, deposition of 15 cm of new sediment.
Pier 64, Seattle, WA	Nearshore capping	0.5-1.5 feet sand (enhanced natural recovery)	1994	4 acres	Metals, PAHs, benzoic acid, PCBs, dibenzofurans and bis (2-ethyhexyl) phthalate	• Subsurface chemistry, thickness rods. • Chemicals below precapping concentrations; either erosion or settlement occurred at portions of cap.
Pine Street Canal Superfund	Canal capping	1.5-4 feet sand/silt cap	July 2003	8 acres	PAHs, NAPL, VOCs and heavy metals	• Sheen and globules of coal tar observed from 2005 to present. Oil booms and other

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Site, Burlington, VT						controls in place to prevent contamination from entering Lake Champlain.
Port of Los Angeles, CA	CAD for 543,000 cy of material	13 feet plus 2 feet of sand	1993	94 acres	Various	• Unknown.
Port Newark Elizabeth, NY/NJ	CAD	Minimum 3 feet over main mound. Minimum 1 foot over apron.	1993/1994	365 acres	Various	• Unknown.
Portland General Electric (PGE) — Station L, OR	Willamette River, ODEQ lead	Sand, gravel and riprap to a thickness of greater than 6 feet	January 1991	Unknown	PCB	• Visual (diver) surveys.
Puget Sound Naval Shipyard Complex Superfund Site (aka Bremerton Naval Complex), WA	Marine capping (Navy lead/CERCLA)	Multilayer cap: 1 foot clean sand, 2 feet native sediment (32 acres), 3 feet clean sediment (13 acres)	2001	45 acres	PCBs and mercury	• Marine tissue and sediment sampling, and bathymetric surveys. • Monitoring underway.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Rahway River/Cytec Industries Inc., Linden, NJ	River capping	Multilayer: two geotextile fabric layers, sand and rip rap	1997	0.5 acre	DDT, DDD, DDE, VOCs and metals	• Semiannual sampling of surrounding sediments (1996-2000).
Rhodia, Inc. — Suttle Road, OR	Oregon Slough (ODEQ lead)	Multilayer: geotextile, 3-9 inches gravel, and 12-19 inches riprap (armor)	2005	¾ acre	Pesticides	• Annual cap inspection and after major flood events. First monitoring report not yet released.
Rotterdam Harbor, Netherlands	CAD Phase 1 cap in approx. 100 feet of water	2-3 feet clay	1981	160 acres	Various chemicals from chemical and petroleum industry	• Unknown.
Rotterdam Harbor, Netherlands	CAD Phase 2 cap in approx. 70 feet of water	2-3 feet clay	1983	Unknown	Various chemicals from chemical and petroleum industry	• Unknown.
St. Lawrence River, NY	Embayment capping, GM Massena Superfund	Multilayer cap: 6 inches each sand, gravel and armor stone	1995	1.7 acres	PCBs	• Visual and diver-assisted inspection. 30 to 35 cy of rock placed within 15 feet of shoreline for purposes of restoration. • Annual Inspection Results:

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
	Site					• First three years: Small near shore areas restored with armor protection.
St. Lawrence River, NY (cont'd)	Embayment capping, GM Massena Superfund Site	Multilayer cap: 6 inches each sand, gravel and armor stone	1995	1.7 acres	PCBs	• 1999 to 2002: no cap repairs were necessary. • 2003, 2004, and 2005 - small areas were restored with additional stone. • 2006: Observations included that the general integrity of the stone cap was undisturbed and in good condition.
Sheboygan Harbor & River Superfund Site, WI	Sediment deposit capping, pilot study, river	Layered design — geotextile, 1 foot gravel with sand and clay, geotextile, 1 foot armor stone	1990	2.5 acres	PCBs	• Visual observation, sediment cores in 1999. • Capped areas appear intact, cores indicate no migration into cap, potential ongoing source in one area.
Silver Lake, MA	Pilot Study	14-inch designed isolation layer (IL) (sand and topsoil) or non-woven geotextile covered by 14-inch IL or composite geotextile covered by 14-inch IL	Pilot studies began in 2006; full-scale implementa-tion anticipated for 2008	~0.8 acres	PCBs	• Sediment consolidation and cap uniformity monitoring; cap material coring and chemical analysis.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Simpson-Tacoma, WA	Nearshore capping, St. Paul Waterway	Ranged from 4-20 feet sand	1988	17 acres	PAHs, dioxins, phenols and PCDFs	• Subsurface, chemistry, surface sediments, benthos, epibenthos and bathymetry. • Surface sampling indicated no chemical migration into cap, healthy aquatic communities, minor erosion of top layer in small area.
Soda Lake, WY	Pilot Study; capping not selected for full-scale remedy	1.5 feet native sand	2000	5.6 acres	PAHs, benzene, heavy metals and NAPL	• Inspection and monitoring were planned, but did not occur.
Soerfjorden, Norway	Embayment capping	1-2 feet sand and geotextile	1991	25 acres	Metals	• Unknown.
Spokane River Upriver Dam PCB Site, WA	River capping (WA Department of Ecology lead/MTCA)	Multilayer: coal, sand and gravel (armor)	2006	3.6 acres	PCBs	• Bathymetric survey and sediment sampling. • Monitoring to begin in 2008.
Spokane River Donkey Island PCB Site, WA	River capping (WA Department of Ecology lead/MTCA)	Clean sand (backfill)	2006	¼ acre	PCB	• Bathymetric survey and sediment sampling. • Monitoring to begin in 2008.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
United Heckathorn Superfund Site, CA	Parr Channel/ Lauritzen Channel	1.5 feet of sand	1996/1997	15 acres	Pesticides (DDT and dieldrin)	• Yearly monitoring to verify the effectiveness of the remedy for a minimum of 5 years including surface waters and biological samples. • Both the initial and second 5-year review reveal that remediation goals for DDT and dieldrin for water and sediments have not been maintained. A focused feasibility study to evaluate alternatives for addressing the remaining contamination is ongoing as of September 2006.
Whatcom Waterway — Log Pond Area, Bellingham, WA	Bay capping (Ecology lead)	3 feet silt-sand	2001	5.6 acres	Mercury, phenol, wood debris	• Sediment and biological samples, cap inspections. • No chemical migration, minor recontamination from resuspension nearby, some wave action-induced erosion at edges.

TABLE 2
SUMMARY OF COMPLETED CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Date Completed	Area Addressed	Chemical Constituents	Monitoring and Results
Wyckoff/ Eagle Harbor Superfund Site, East Unit, WA	Embayment capping	Phase I: 3 feet clean river sediment Phase II: 3 feet clean sand	Phase I: 1994 Phase II: 2001 Phase III: 2002	Phase I: 54 acres Phase II: 15 acres Phase III: Modifications made to Phase II cap	PAHs, creosote and mercury	• Water/sediment chemistry, sediment traps, profile camera bathymetry, benthos. • Ongoing, creosote marbles on sediment surface from unknown source. Cap is working well and is preventing chemical migration.
Wyckoff/ Eagle Harbor Superfund Site, West Unit, WA	Embayment capping	Thin quarry sand cap (0.5 feet) over 6 acres Thick quarry sand cap (3 feet) over 0.6 acres	1997	6.6 acres	PAHs and mercury	• Bathymetry, surface chemistry. • Post-verification surface sediment samples have met the cleanup criteria established for the project. Monitoring will continue. Post-implementation surveys identified 16 discrete cap areas lacking in minimum thickness. To remedy this, an additional 1,000 cy was added.

TABLE 3
SUMMARY OF PENDING CAPPING PROJECTS

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Proposed Date of Implementation	Area to be Addressed	Chemical Constituents to be Addressed	Proposed Monitoring
Brooklyn Borough Gas Works Site — OU #2 - Coney Island Creek, NY	Creek capping, post-dredging, State lead	Up to 3 feet of sand and/or silty-sand material and a filter fabric or geotextile	2007	~7 acres	PAHs	Sediment and surface-water samples, bathymetry
Eagle River Flats (OU #3), Fort Richardson Superfund Site, AK	Remedial action (federal lead/RCRA)	1 to 1.5 feet of pit-run gravel over geofabric layer	2008 (deferred until effectiveness of pond pumping known)	Limited to areas where pond pumping unsuccessful (<5m widths)	White phosphorus	Waterfowl health, physical robustness, and settling effectiveness
Fox River, WI	River capping, contingency remedy, post-dredging, State lead	Sand and gravel of unknown thickness	Unknown	~70 acres (OU #3 and #4)	PCBs, dioxins, furans, metals	Bathymetric or side-scan sonar profiling, sediment and cap sampling, capture and analysis of porewater, diver inspections
	River capping, proposed change	6 to 16 inches of sand and gravel, or 33-inch sand/ quarry cap (depending on area)	Unknown	~660 acres (OU #2 through #5)	PCBs, dioxins, furans, metals	Physical integrity monitoring (e.g., bathymetric surveys), chemical analyses of surface sediments and cores
Onondaga Lake Superfund Site (Onondaga Lake Bottom Subsite — OU #2), NY	Lake capping, post-dredging	Multilayer: mixing layer, chemical isolation layer (min. 12 inches), habitat restoration layer (min. 12 inches), and erosion/armor layer	2011	425 acres	Mercury, heavy metals, PCBs, VOCs, PAHs	Sampling of the cap to determine its integrity (chemically and structurally)

TABLE 3
SUMMARY OF PENDING CAPPING PROJECTS

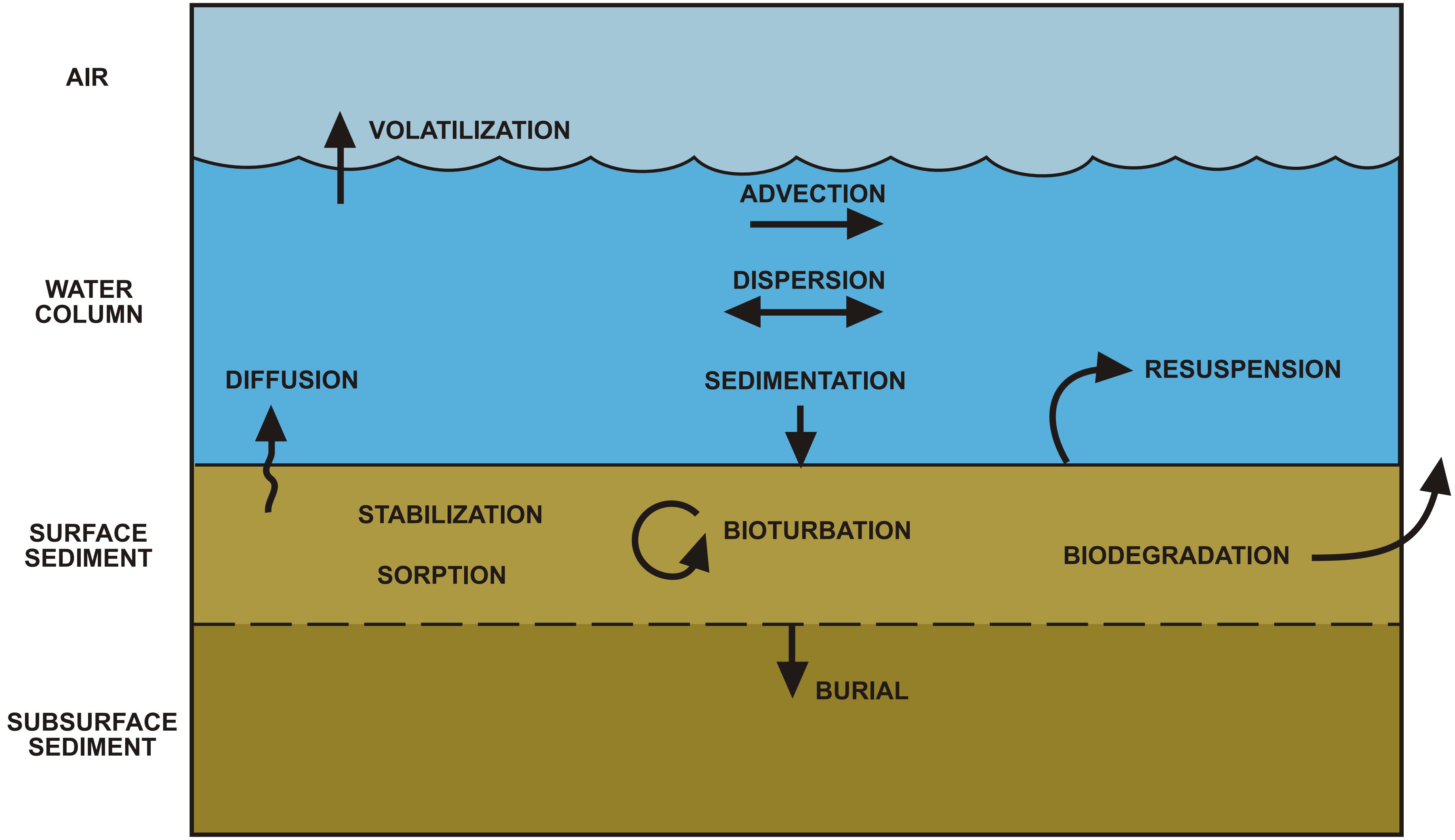
TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Site	Activity Description	Cap/Armor Detail	Proposed Date of Implementation	Area to be Addressed	Chemical Constituents to be Addressed	Proposed Monitoring
Portland Harbor Superfund Site — Port of Portland Marine Terminal 4, OR	Early action cleanup, Willamette River capping	Multilayer: 6- to 12-inch base organoclay, silt-gravel, riprap armor	2007-2008	8.7 acres	PCBs, DDT, heavy metals, PAHs	Unknown
St. Louis River/ Interlake/Duluth Tar Superfund Site (Sediment OU), MN	Bay capping; state lead	3 feet of sand	Began in 2006 — anticipated end in 2009	30 acres	PAHs	Inspection, sediment and biota monitoring, pore water, surface water
St. Maries Creosote Superfund Site, ID	Proposed NPL Site; 2006 Proposed Plan; offshore capping	2-foot thick conventional cap; sand and gravel cap with armor stone; methane collection system	Unknown – Record of Decision is not yet signed	Unknown	creosote (DNAPL and LNAPL), PAHs	Bathymetric surveys, surface sediment sampling, subsurface sediment coring, hydrogeologic and capping models
Zidell Site, OR	Willamette River nearshore capping, State lead	2-foot layer of sand armored with 1 foot of 2- to 6-inch rounded river rock	2010	8 acres	PCBs, metals, petroleum hydrocarbons, PAHs	Annual visual inspection for at least three years, bathymetric surveys, sediment testing

TABLE 4
ENVIRONMENTAL DREDGING TECHNOLOGIES

TECHNOLOGY APPLICATIONS FOR OPERABLE UNIT 3

Dredge Technology	Sediment Resuspension	Availability	Site Compatibility / Technical Feasibility	Percent Solids	Production Rate	Past Performance
Open Clamshell Bucket	High due to sloughing of cut, washout and spillage from open bucket, etc.	TBD	Generally compatible with site characteristics; debris can cause problems and increase resuspension. Higher precision than excavators.	Near in-situ.	Rates for 5- to 10-cy buckets range from about 75 to 300 cy/hr. Larger buckets are available up to about 60 cy and may produce 600+ cy/hr. Production is typically less on slopes (40 to 100 cy/hr). May be difficult or unable to dig through hard sediments.	Used widely in U.S.
Enclosed Clamshell Bucket	Low to moderate. Up to 25 to 70% reduction in resuspension compared to open clamshell.	TBD	Generally compatible with site characteristics; debris can cause problems and increase resuspension. Higher precision than excavators.	Near in-situ.	Rates for 5- to 10-cy buckets range from about 75 to 300 cy/hr. Larger buckets are available up to about 60 cy and may produce 600+ cy/hr. Production is typically less on slopes (40 to 100 cy/hr).	Evaluation by USACE in 1982 showed significant reduction in turbidity.
Barge-Mounted Excavator with Conventional Bucket	High. Similar to open clamshell.	TBD	Generally compatible with site characteristics; fairly good debris handling capabilities. Higher precision than cable-operated clamshells.	Near in-situ.	Production rates are likely slightly lower than crane operated clamshell dependent on bucket size.	An instrumented excavator was used to dredge 162,000 cy of PAH contaminated sediments in Bayou Bonfouca, LA.
Barge-Mounted Excavator with Bucket-Closing Mechanism	Low to moderate. Less resuspension as compared to open clamshell and conventional excavator.	TBD	Generally compatible with site characteristics; debris may cause difficulty associated with closing mechanism. Higher precision than cable-operated clamshells.	Near in-situ.	Production rates are likely slightly lower than crane operated clamshell dependent on bucket size.	Visor Grab was tested for Environment Canada's Great Lakes project. Additional testing may be needed.
Cutterhead	Low to moderate. Less resuspension than open-bucket mechanical dredges, but dependent on dredge design and operation.	TBD	Generally compatible with site characteristics; relatively poor debris handling capabilities.	5% to 20% by weight	Rates for 6- to 12-inch pumps range from about 25 to 120 cy/hr. Larger pumps are available up to about 30-inches and may produce 1000+ cy/hr.	Used widely in the U.S. for maintenance and environmental dredging (e.g. Sitcum Waterway, Tacoma, WA).
Horizontal Auger	Low to moderate. Less resuspension mechanical dredges and possibly less than cutterhead dredge.	TBD	Generally compatible with site characteristics; relatively poor debris handling capabilities.	5% to 20% by weight	Rates for 6- to 12-inch pumps range from about 25 to 120 cy/hr.	Developed in the U.S. and used on several projects (e.g., Cold Spring, NY)
Plain Suction	Low to moderate; no mechanical action to dislodge material.	TBD	Better suited for smaller dredge volumes.	5% to 20% by weight	25 to 120 cy/hr.	"Matchbox" dredge was used in the Calumet Harbor demonstration project by the Waterways Experiment Station.
Diver-Assisted Hydraulic Suction Dredge	Low due to precision, small size of dredge head, and slow operation.	TBD	May be well suited for certain areas such as areas with limited access (e.g between piles); generally not well suited for large volumes.	<5% by weight	15 to 30 cy/hr.	Used for removal in smaller areas (e.g., Manistique River, MI; removal of 8,000 cy of PCB contaminated sediments)
Oozer Pump	Low. However, debris can clog pump causing increased resuspension.	TBD	Generally compatible with site characteristics; debris can cause problems and increase resuspension.	25% to 80% by weight	40 to 300 cy/hr.	Used extensively in Japan.
Pneuma Pump	Low. However, debris can clog pump causing increased resuspension.	TBD	Generally compatible with site characteristics; debris can cause problems and increase resuspension.	25% to 80% by weight	40 to 300 cy/hr.	Duwamish River, Seattle, WA, 1976, PCB cleanup, very low turbidity.
Toyo Pump	Low	TBD	Generally compatible with site characteristics; can handle up to 5-inch rock.	Up to about 70% by weight	30 to 200 cy/hr.	Used to remove 32,000 cy of highly contaminated sediments from the Hylebos Waterway in Tacoma, WA.
Eddy Pump	Low	TBD	Generally compatible with site characteristics; can handle up to 5-inch rock. Suitable to pump slurry over relatively long distances.	Up to about 70% by weight	100 to 300 cy/hr.	Has been used on several environmental dredging projects e.g. removing 50,000 cy sediment in Sarnia, ONT.



MONITORED NATURAL RECOVERY
PROCESSES WHEN
SOURCES ARE CONTROLLED

ARCADIS
Infrastructure, environment, facilities

FIGURE
1

Appendix G

Statistical Analysis of Mercury Concentrations in River Sediment

ARCADIS BBL

ARCADIS U.S., Inc.
8 South River Road
Cranbury
New Jersey 08512
Tel 609.860.0590
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MEMO

To:
Betsy Henry, Exponent, Inc.

Copies:
Katie Winogrodzki, 3M
DJ Camerson, Esq., Bressler Amery and Ross
Moh Mohiuddin, ARCADIS

From:
Kris D. Hallinger, ARCADIS BBL

Date:
August 3, 2007

ARCADIS BBL Project No.:
NJ000514

Subject:
Background Comparison Study

Background Comparison
Raritan River Sediment PCOC Concentrations
Horseshoe Road/Atlantic Resources Corporation (ARC) OU-3 Site
Sayreville, New Jersey

Arsenic and mercury concentrations in Raritan River sediment at the Horseshoe Road/ARC OU-3 site (the “site”) were compared to background, or reference site, concentrations to assess whether site sediment concentrations (for a given metal and depth interval) are statistically different from background sediment concentrations. The average concentration of arsenic and mercury in sediment sample locations in the river adjacent to the site were compared to average concentrations of these metals in sediment collected at 5 nearby reference locations in the river. Arsenic concentrations in the river surface sediment samples ranged from 9.13 to 654 mg/kg with a mean value of 120 mg/kg and standard deviation of 132.6. Arsenic concentrations in the reference surface samples ranged from 6.0 to 98.9 mg/kg with a mean value of 43.2 mg/kg and standard deviation of 35.3. Mercury concentrations in the river surface sediment samples ranged from 0.026 to 4.03 mg/kg with a mean value of 1.6 mg/kg and standard deviation of 1.03. Mercury concentrations in the reference surface sediment samples ranged from 0.078 to 3.88 mg/kg with a mean value of 1.29 mg/kg and standard deviation of 1.52.

Statistical comparisons of the arsenic and mercury data sets to site-specific background concentrations were conducted using ProUCL Version 4.0 (USEPA, 2007a) and the recommendations provided in the associated technical documentation (USEPA, 2007b, 2007c). The appropriate statistical test was chosen based on the distribution of both the site-specific and the background data. The distribution of the data in each dataset was tested using the Shapiro-Wilk test (USEPA, 2002, 2007b, 2007c). The results of the Shapiro-Wilk tests indicate that data exhibit either normal, log-normal, or both normal and log-normal distributions in both site and background datasets for each metal and depth interval.

The t-test is appropriate for metals that are normally or log-normally distributed in both site and background sediments (USEPA, 2002). Student's t-test is used in cases where the site data set and background dataset have equal variances, whereas the Satterthwaite's t-test is used in cases where variances are not equal. The nonparametric Wilcoxon-Mann-Whitney (WMW) test is appropriate for site and background data sets that exhibit the same shape and variance, but neither data set needs to fit a normal or lognormal distribution (USEPA, 2002; 2007d). Because the WMW test is robust with respect to deviations from normality and the presence of outliers, it is useful to consider results of the WMW test along with the results of the t-test.

Both the t-test and the WMW test were conducted to test for statistical differences between site and background sediment concentrations of mercury and arsenic at a 95% confidence level ($\alpha = 0.05$) (USEPA, 2002). The results of the statistical comparisons are summarized in the table below.

Table 1 – Statistical Test Results

		t-Test[1] Results				Wilcoxon-Mann-Whitney Test Results			
Metal	**Depth Interval (inches)**	**Test Statistic[2]**	**Critical Value[3]**	**p-Value**	**Site Greater Than Background?**	**Test Statistic[2]**	**Critical Value[3]**	**p-Value[4]**	**Site Greater Than Background?**
Mercury	0-6	0.64	1.696	0.264	No	92	114	0.14	No
Mercury	6-18	1.595	1.729	0.064	No	62	60	0.0379	**Yes**
Mercury	18-30	0.975	1.729	0.171	No	54	60	0.132	No
Mercury	30-42	0.523	1.729	0.304	No	50	60	0.216	No
Arsenic	0-6	2.593	1.706	0.008	**Yes**	101	114	0.0628	No
Arsenic	6-18	2.548	1.734	0.01	**Yes**	65	60	0.0215	**Yes**
Arsenic	18-30	3.083	1.729	0.003	**Yes**	64	60	0.0262	**Yes**
Arsenic	30-42	2.162	1.729	0.022	**Yes**	64	60	0.0262	**Yes**

Notes:
1. Student's t-test conducted when background and Site datasets have equal variance; Satterwaite's t-test conducted when background and site datasets do not have equal variance.
2. Test statistic reported as t-test value for t-test results and U-Stat for Wilcoxon-Mann-Whitney test results.
3. Critical value reported for associated test statistic.
4. p-Value, as computed by ProUCL 4.0, is an approximate value only.

Results of the above statistical evaluation using the t-test indicate that average concentrations of mercury in site sediments are not statistically different from average surface sediment background concentrations in each of the four depth intervals. Results for mercury using the WMW test generally concur, with the exception of the site data for the 6-18 inch interval; however, given that both background and site data are normally distributed, results for the t-test are considered more reliable. For arsenic, the results suggest that concentrations in site sediments are statistically greater than background. As with mercury, results of the WMW test generally concur with results using the t-test. Results of the WMW test suggest that arsenic concentration in site data for the 0-6 inch interval are not greater than background; however the data are both lognormally distributed, suggesting the results based on the t-test may be more reliable. Additional information related to the statistical analysis of these data sets is provided in the following pages.

References:

USEPA. 2002. Guidance for comparing background and chemical concentrations in soil for CERCLA sites. Office of Emergency and Remedial Response. EPA 540-R-01-003. OSWER 9285.7-41.

USEPA. 2007a. ProUCL 4.0. A Statistical Software Package. Office of Research and Development, National Exposure Research Laboratory, Environmental Sciences Division, Las Vegas, Nevada.

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USEPA. 2007c. ProUCL 4.0 User Guide. Office of Research and Development, National Exposure Research Laboratory, Environmental Sciences Division. EPA/600/R-07/038.

USEPA. 2007d. Performance of Statistical Tests for Site Versus Background Soil Comparisons When Distributional Assumptions are Not Met. Office of Research and Development. EPA/600/R-07/020.

Methods of Background Comparison for River Sediment
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

Box Plots	Hypothesis Testing - Parametric Student's t-Test and Satterthwaite t-Test	Hypothesis Testing - Wilcoxon-Mann-Whitney Test	Upper Tolerance Limit (UTL) Approach
Visual comparison of data distribution between the background dataset and site dataset for each depth interval. Box defined by 1st and 3rd quartiles (interquartile range, IQR); central line = median of dataset; error bars defined range of dataset; potential outlier idenfied with triangle.	Parametric method used to compare the means of two populations. t-Test is robust to small deviations from normality but not robust with respect to outliers. Student's t-test assumes equality of variances of the background and site datasets. If variances are not equal and normality assumptions are valid, apply Satterthwaite's t-test. If variances are not equal and normality assumptions are not valid, apply Wilcoxon-Mann Whitney test. F-test used to test for equality of variances.	Nonparametric test to determine whether a difference exists between the site and background population distributions. Method does not require datasets of normal distribution, but background and site datasets need to have similar distributions; robust with respect to outliers; allows for nondetect measurements to be present in both datasets.	Calculation of UTL and point-by-point comparison to site sediment data; Because the sample size of the background dataset is small, the UTL is set to the maximum detected concentration.

Results of Background Comparison for River Sediment - Arsenic
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

Analyte	Depth Interval (in)	Distribution	Box Plots	Hypothesis Testing - Parametric Student's t-Test and Satterthwaite t-Test	Hypothesis Testing - Wilcoxon-Mann-Whitney Test	Upper Tolerance Limit (UTL) Approach
Arsenic	Background	(Log-)Normal	Maximum detected concentration identified as potential outlier.	--	--	UTL = 98.9 mg/kg
Arsenic	0 - 6	Log-normal	Minimal overlap of IQR(site) and IQR(bkgd). Minimum detected concentration of the site overlaps IQR(bkgd). Consistent with box plots from other depths. Potential outlier idenfied in site data.	F-test: two variances are not equal; p-value = 0.019 Student's t-Test: Do not reject null hypothesis, conclude Site <= Background, p-value = 0.107 <u>Satterthwaite Test: Reject null hypothesis, conclude Site > Background, p-value = 0.008</u>	Approximate p-value = 0.0628 Do not reject null hypothesis, conclude Site <= Background	12/28 samples exceed UTL (Sample locations RSD04, RSD06 through RSD08, RSD10 through RSD12, RSD14, 2 through 4, and SD31)
Arsenic	6 - 18	Log-normal	No overlap of IQR(site) and IQR(bkgd). Minimum detected concentration of the site overlaps IQR(bkgd). Consistent with box plots from other depths.	F-test: two variances are not equal; p-value = 0.005 Student's t-Test: Do not reject null hypothesis, conclude Site <= Background, p-value = 0.08 <u>Satterthwaite Test: Reject null hypothesis, conclude Site > Background, p-value = 0.01</u>	Approximate p-value = 0.0215 Reject null hypothesis, conclude Site > Background	10/16 samples exceed UTL (Sample locations RSD03 through RSD12)
Arsenic	18 - 30	(Log-)Normal	No overlap of IQR(site) and IQR(bkgd). Minimum detected concentration of the site overlaps IQR(bkgd). Consistent with box plots from other depths.	F-test: two variances are not equal; p-value = 0.038 Student's t-Test: Do not reject null hypothesis, conclude Site <= Background, p-value = 0.035 <u>Satterthwaite Test: Reject null hypothesis, conclude Site > Background, p-value = 0.003</u>	Approximate p-value = 0.0262 Reject null hypothesis, conclude Site > Background	8/16 samples exceed UTL (Sample locations RSD03 through RSD10)
Arsenic	30 - 42	Normal	No overlap of IQR(site) and IQR(bkgd). Minimum detected concentration of the site overlaps IQR(bkgd). Consistent with box plots from other depths.	F-test: two variances appear to be equal; p-value = 0.09 <u>Student's t-Test: Reject null hypothesis, conclude Site > Background, p-value = 0.022</u> Satterthwaite Test: Reject null hypothesis, conclude Site > Background, p-value = 0.002	Approximate p-value = 0.0262 Reject null hypothesis, conclude Site > Background	9/16 samples exceed UTL (Sample locations RSD03 through RSD10 and RSD17)

<u>Notes:</u>
in = inches
IQR = interquartile range
bkgd = background
1. Distribution assessed using the Shapiro-Wilk test to test for normality or log-normality of a dataset
   - Normal = data fits a normal distribution
   - Log-normal = data fits a log-normal distribution
   - (Log-)Normal = data fits both a normal and log-normal distribution
2. Null hypothesis = the concentrations in the potentially impacted sites areas do not exceed (or are less than equal) background concentrations
3. A p-value is the smallest value for which the null hypothesis is rejected in favor of the alternative hypotheses. If the computed p-value is smaller than the specified value of α (default=0.05), the conclusion is to reject the null hypothesis based upon the collected dataset used in the various computations.
4. Visual review of quartile-quartile plots does not suggest multiple populations are present within each depth interval.

Results of Background Comparison
River Sediment - Arsenic Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

t-Test Site vs Background Comparison for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference (S)	0
Selected Null Hypothesis	Site or AOC Mean Less Than or Equal to Background Mean (Form 1)
Alternative Hypothesis	Site or AOC Mean Greater Than the Background Mean

Area of Concern Data: As(0 - 6in.)

Background Data: As(background)

Raw Statistics

	Site	Background
Number of Valid Samples	28	5
Number of Distinct Samples	27	5
Minimum	9.13	5.95
Maximum	654	98.9
Mean	120	43.25
Median	71.3	43.1
SD	132.6	35.26
SE of Mean	25.06	15.77

Site vs Background Two-Sample t-Test

H0: Mu of Site - Mu of Background <= 0

Method	DF	t-Test Value	Critical t (0.050)	P-Value
Pooled (Equal Variance)	31	1.271	1.696	0.107
Satterthwaite (Unequal Variance)	25.6	2.593	1.706	0.008

Pooled SD 124.412

Conclusion with Alpha = 0.050

* Student t (Pooled) Test: Do Not Reject H0, Conclude Site <= Background
* Satterthwaite Test: Reject H0, Conclude Site > Background

Test of Equality of Variances

Numerator DF	Denominator DF	F-Test Value	P-Value
27	4	14.144	0.019

Conclusion with Alpha = 0.05

* Two variances are not equal

Results of Background Comparison
River Sediment - Arsenic Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

t-Test Site vs Background Comparison for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference (S)	0
Selected Null Hypothesis	Site or AOC Mean Less Than or Equal to Background Mean (Form 1)
Alternative Hypothesis	Site or AOC Mean Greater Than the Background Mean

Area of Concern Data: As(6 - 18 in.)

Background Data: As(background)

Raw Statistics

	Site	Background
Number of Valid Samples	16	5
Number of Distinct Samples	16	5
Minimum	20.9	5.95
Maximum	845	98.9
Mean	173.7	43.25
Median	135	43.1
SD	194.9	35.26
SE of Mean	48.72	15.77

Site vs Background Two-Sample t-Test

H0: Mu of Site - Mu of Background <= 0

Method	DF	t-Test Value	Critical t (0.050)	P-Value
Pooled (Equal Variance)	19	1.464	1.729	0.08
Satterthwaite (Unequal Variance)	17.6	2.548	1.734	0.01

Pooled SD 173.904

Conclusion with Alpha = 0.050

* Student t (Pooled) Test: Do Not Reject H0, Conclude Site <= Background
* Satterthwaite Test: Reject H0, Conclude Site > Background

Test of Equality of Variances

Numerator DF	Denominator DF	F-Test Value	P-Value
15	4	30.54	0.005

Conclusion with Alpha = 0.05

* Two variances are not equal

Results of Background Comparison
River Sediment - Arsenic Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

t-Test Site vs Background Comparison for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference (S)	0
Selected Null Hypothesis	Site or AOC Mean Less Than or Equal to Background Mean (Form 1)
Alternative Hypothesis	Site or AOC Mean Greater Than the Background Mean

Area of Concern Data: As(18 - 30 in.)

Background Data: As(background)

Raw Statistics

	Site	Background
Number of Valid Samples	16	5
Number of Distinct Samples	16	5
Minimum	11.2	5.95
Maximum	436	98.9
Mean	142.2	43.25
Median	110.1	43.1
SD	111.7	35.26
SE of Mean	27.94	15.77

Site vs Background Two-Sample t-Test

H0: Mu of Site - Mu of Background <= 0

Method	DF	t-Test Value	Critical t (0.050)	P-Value
Pooled (Equal Variance)	19	1.919	1.729	0.035
Satterthwaite (Unequal Variance)	18.9	3.083	1.729	0.003

Pooled SD 100.598

Conclusion with Alpha = 0.050

* Student t (Pooled) Test: Do Not Reject H0, Conclude Site <= Background
* Satterthwaite Test: Reject H0, Conclude Site > Background

Test of Equality of Variances

Numerator DF	Denominator DF	F-Test Value	P-Value
15	4	10.042	0.038

Conclusion with Alpha = 0.05

* Two variances are not equal

Results of Background Comparison
River Sediment - Arsenic Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

t-Test Site vs Background Comparison for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference (S)	0
Selected Null Hypothesis	Site or AOC Mean Less Than or Equal to Background Mean (Form 1)
Alternative Hypothesis	Site or AOC Mean Greater Than the Background Mean

Area of Concern Data: As(30 - 42 in.)

Background Data: As(background)

Raw Statistics

	Site	Background
Number of Valid Samples	16	5
Number of Distinct Samples	16	5
Minimum	10.7	5.95
Maximum	278	98.9
Mean	131.8	43.25
Median	117.4	43.1
SD	88.11	35.26
SE of Mean	22.03	15.77

Site vs Background Two-Sample t-Test

H0: Mu of Site - Mu of Background <= 0

Method	DF	t-Test Value	Critical t (0.050)	P-Value
Pooled (Equal Variance)	19	2.162	1.729	0.022
Satterthwaite (Unequal Variance)	17.3	3.269	1.74	0.002

Pooled SD 79.942

Conclusion with Alpha = 0.050

* Student t (Pooled) Test: Reject H0, Conclude Site > Background
* Satterthwaite Test: Reject H0, Conclude Site > Background

Test of Equality of Variances

Numerator DF	Denominator DF	F-Test Value	P-Value
15	4	6.243	0.09

Conclusion with Alpha = 0.05

* Two variances appear to be equal

Results of Background Comparison
River Sediment - Arsenic Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

Wilcoxon-Mann-Whitney Site vs Background Comparison Test for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference	0
Selected Null Hypothesis	Site or AOC Mean/Median Less Than or Equal to Background Mean/Median (Form 1)
Alternative Hypothesis	Site or AOC Mean/Median Greater Than Background Mean/Median

Area of Concern Data: As(0 - 6in.)

Background Data: As(background)

Raw Statistics

	Site	Background
Number of Valid Samples	28	5
Number of Distinct Samples	27	5
Minimum	9.13	5.95
Maximum	654	98.9
Mean	120	43.25
Median	71.3	43.1
SD	132.6	35.26
SE of Mean	25.06	15.77

Wilcoxon-Mann-Whitney (WMW) Test

H0: Mean/Median of Site or AOC <= Mean/Median of Background

Site Rank Sum W-Stat	507
WMW Test U-Stat	101
WMW Critical Value (0.050)	114
Approximate P-Value	0.0628

Conclusion with Alpha = 0.05

Do Not Reject H0, Conclude Site <= Background

Results of Background Comparison
River Sediment - Arsenic Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

Wilcoxon-Mann-Whitney Site vs Background Comparison Test for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference	0
Selected Null Hypothesis	Site or AOC Mean/Median Less Than or Equal to Background Mean/Median (Form 1)
Alternative Hypothesis	Site or AOC Mean/Median Greater Than Background Mean/Median

Area of Concern Data: As(6 - 18 in.)

Background Data: As(background)

Raw Statistics

	Site	Background
Number of Valid Samples	16	5
Number of Distinct Samples	16	5
Minimum	20.9	5.95
Maximum	845	98.9
Mean	173.7	43.25
Median	135	43.1
SD	194.9	35.26
SE of Mean	48.72	15.77

Wilcoxon-Mann-Whitney (WMW) Test

H0: Mean/Median of Site or AOC <= Mean/Median of Background

Site Rank Sum W-Stat	201
WMW Test U-Stat	65
WMW Critical Value (0.050)	60
Approximate P-Value	0.0215

Conclusion with Alpha = 0.05

Reject H0, Conclude Site > Background

Results of Background Comparison
River Sediment - Arsenic Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

Wilcoxon-Mann-Whitney Site vs Background Comparison Test for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference	0
Selected Null Hypothesis	Site or AOC Mean/Median Less Than or Equal to Background Mean/Median (Form 1)
Alternative Hypothesis	Site or AOC Mean/Median Greater Than Background Mean/Median

Area of Concern Data: As(18 - 30 in.)

Background Data: As(background)

Raw Statistics

	Site	Background
Number of Valid Samples	16	5
Number of Distinct Samples	16	5
Minimum	11.2	5.95
Maximum	436	98.9
Mean	142.2	43.25
Median	110.1	43.1
SD	111.7	35.26
SE of Mean	27.94	15.77

Wilcoxon-Mann-Whitney (WMW) Test

H0: Mean/Median of Site or AOC <= Mean/Median of Background

Site Rank Sum W-Stat	200
WMW Test U-Stat	64
WMW Critical Value (0.050)	60
Approximate P-Value	0.0262

Conclusion with Alpha = 0.05

Reject H0, Conclude Site > Background

Results of Background Comparison
River Sediment - Arsenic Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

Wilcoxon-Mann-Whitney Site vs Background Comparison Test for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference	0
Selected Null Hypothesis	Site or AOC Mean/Median Less Than or Equal to Background Mean/Median (Form 1)
Alternative Hypothesis	Site or AOC Mean/Median Greater Than Background Mean/Median

Area of Concern Data: As(30 - 42 in.)

Background Data: As(background)

Raw Statistics

	Site	Background
Number of Valid Samples	16	5
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SD	88.11	35.26
SE of Mean	22.03	15.77

Wilcoxon-Mann-Whitney (WMW) Test

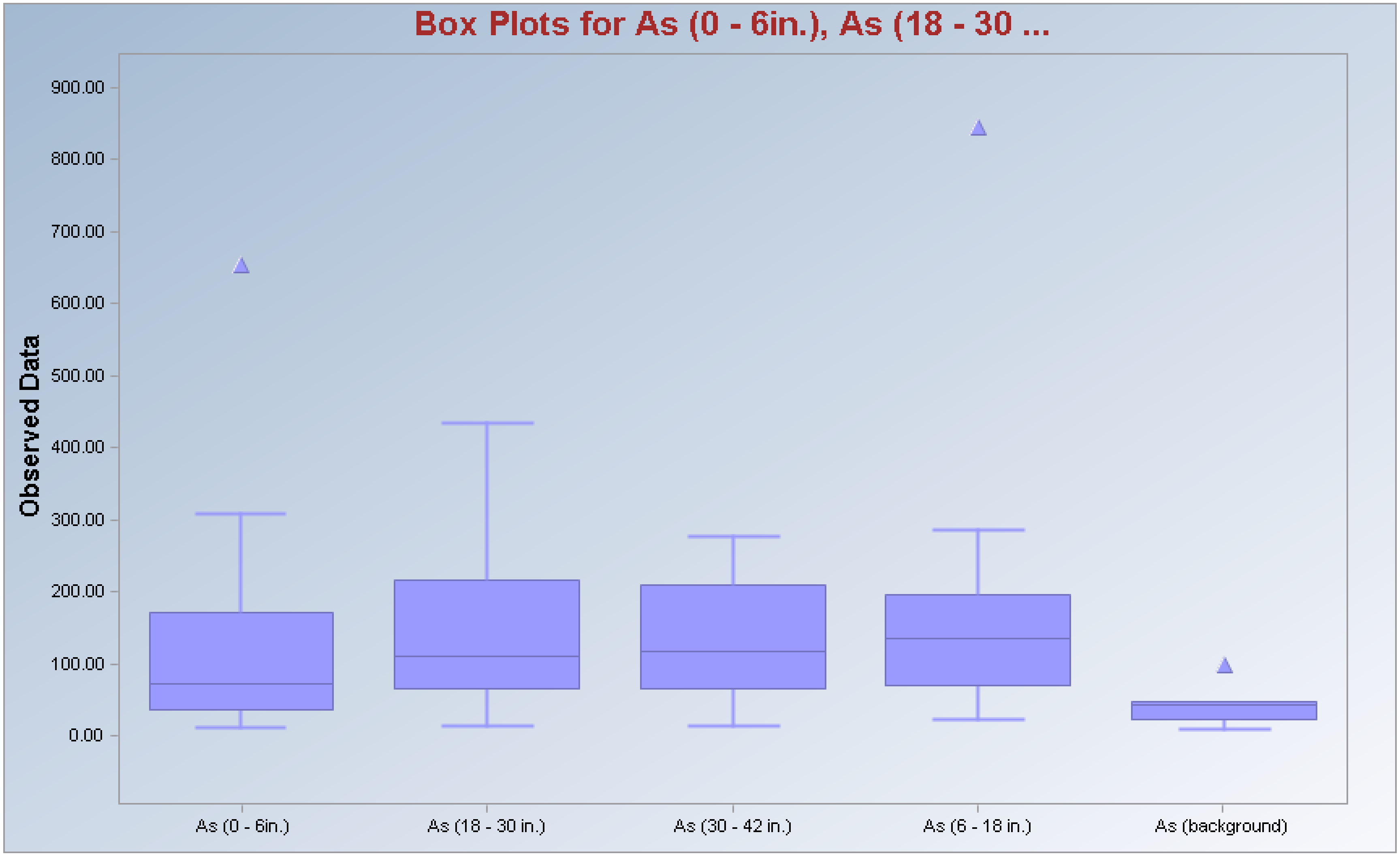
H0: Mean/Median of Site or AOC <= Mean/Median of Background

Site Rank Sum W-Stat	200
WMW Test U-Stat	64
WMW Critical Value (0.050)	60
Approximate P-Value	0.0262

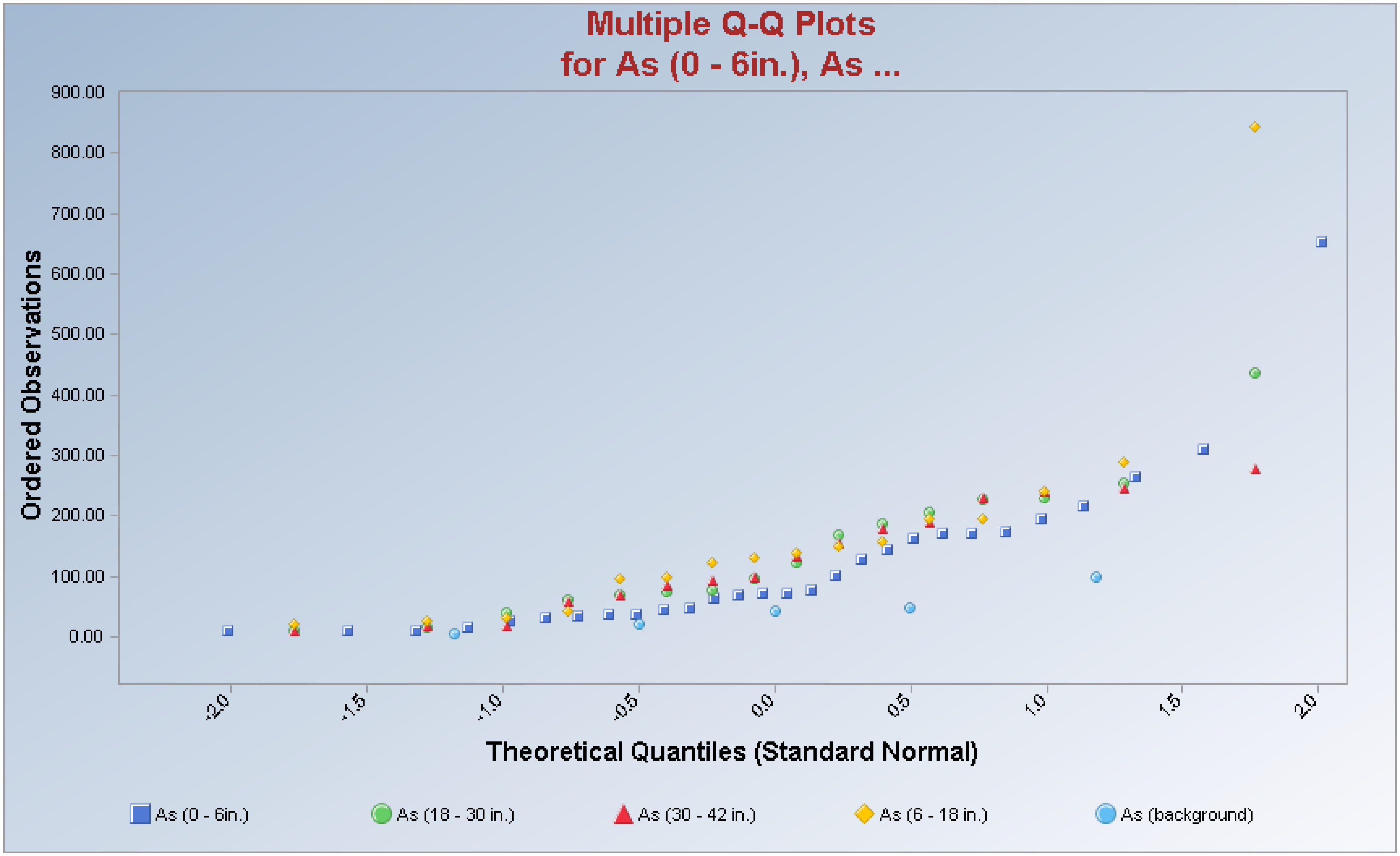
Conclusion with Alpha = 0.05

Reject H0, Conclude Site > Background

Box Plots for Arsenic



Quartile-Quartile Plots for Arsenic



Methods of Background Comparison for River Sediment
Horsehoe Road/ARC OU3 Site
Sayreville, New Jersey

Box Plots	Hypothesis Testing - Parametric Student's t-Test and Satterthwaite t-Test	Hypothesis Testing - Wilcoxon-Mann-Whitney Test	Upper Tolerance Limit (UTL) Approach
Visual comparison of data distribution between the background dataset and site dataset for each depth interval. Box defined by 1st and 3rd quartiles (interquartile range, IQR); central line = median of dataset; error bars defined range of dataset; potential outlier idenfied with triangle.	Parametric method used to compare the means of two populations. t-Test is robust to small deviations from normality but not robust with respect to outliers. Student's t-test assumes equality of variances of the background and site datasets. If variances are not equal and normality assumptions are valid, apply Satterthwaite's t-test. If variances are not equal and normality assumptions are not valid, apply Wilcoxon-Mann Whitney test. F-test used to test for equality of variances.	Nonparametric test to determine whether a difference exists between the site and background population distributions. Method does not require datasets of normal distribution, but background and site datasets need to have similar distributions; robust with respect to outliers; allows for nondetect measurements to be present in both datasets.	Calculation of UTL and point-by-point comparison to site sediment data; Because the sample size of the background dataset is small, the UTL is set to the maximum detected concentration.

Results of Background Comparison for River Sediment - Mercury
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

Analyte	Depth Interval (in)	Distribution	Box Plots	Hypothesis Testing - Parametric Student's t-Test and Satterthwaite t-Test	Hypothesis Testing - Wilcoxon-Mann-Whitney Test	Upper Tolerance Limit (UTL) Approach
Mercury	Background	(Log-)Normal	Maximum detected concentration identified as potential outlier.	--	--	UTL = 3.88 mg/kg
Mercury	0 - 6	Normal	Some overlap of IQR(site) and IQR(bkgd). Minimum detected concentration of the site overlaps IQR(bkgd) and minimum detect background concentration. Overlaps with box plots from other depths.	F-test: two variances appear to be equal; p-value = 0.197 Student's t-Test: Do not reject null hypothesis, conclude Site <= Background, p-value = 0.264 Satterthwaite Test: Do not reject null hypothesis, conclude Site <= Background, p-value = 0.325	Approximate p-value = 0.14 Do not reject null hypothesis, conclude Site <= Background	2/28 samples exceed UTL (Sample locations 4 and 8)
Mercury	6 - 18	(Log-)Normal	No overlap of IQR(site) and IQR(bkgd). Minimum detected concentration of the site overlaps IQR(bkgd). Overlaps with box plots from other depths.	F-test: two variances appear to be equal; p-value = 0.396 Student's t-Test: Do not reject null hypothesis, conclude Site <= Background, p-value = 0.064 Satterthwaite Test: Do not reject null hypothesis, conclude Site <= Background, p-value = 0.111	Approximate p-value = 0.0379 Reject null hypothesis, conclude Site > Background	2/16 samples exceed UTL (Sample locations RSD06 and RSD08)
Mercury	18 - 30	Normal	Some overlap of IQR(site) and IQR(bkgd). Minimum detected concentration of the site overlaps IQR(bkgd) and minimum detect background concentration. Overlaps with box plots from other depths.	F-test: two variances appear to be equal; p-value = 0.289 Student's t-Test: Do not reject null hypothesis, conclude Site <= Background, p-value = 0.171 Satterthwaite Test: Do not reject null hypothesis, conclude Site <= Background, p-value = 0.227	Approximate p-value = 0.132 Do not reject null hypothesis, conclude Site <= Background	0/16 samples exceed UTL
Mercury	30 - 42	Normal	Some overlap of IQR(site) and IQR(bkgd). Minimum detected concentration of the site overlaps IQR(bkgd) and minimum detect background concentration. Overlaps with box plots from other depths.	F-test: two variances appear to be equal; p-value = 0.279 Student's t-Test: Do not reject null hypothesis, conclude Site <= Background, p-value = 0.304 Satterthwaite Test: Do not reject null hypothesis, conclude Site <= Background, p-value = 0.342	Approximate p-value = 0.216 Do not reject null hypothesis, conclude Site <= Background	0/16 samples exceed UTL

Notes:
in = inches
IQR = interquartile range
bkgd = background
1. Distribution assessed using the Shapiro-Wilk test to test for normality or log-normality of a dataset
   Normal = data fits a normal distribution
   Log-normal = data fits a log-normal distribution
   (Log-)Normal = data fits both a normal and log-normal distribution
2. Null hypothesis = the concentrations in the potentially impacted sites areas do not exceed (or are less than equal) background concentrations
3. A p-value is the smallest value for which the null hypothesis is rejected in favor of the alternative hypotheses. If the computed p-value is smaller than the specified value of α (default=0.05), the conclusion is to reject the null hypothesis based upon the collected dataset used in the various computations.
4. Visual review of quartile-quartile plots does not suggest multiple populations are present within each depth interval.

Results of Background Comparison
River Sediment - Mercury Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

t-Test Site vs Background Comparison for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference (S)	0
Selected Null Hypothesis	Site or AOC Mean Less Than or Equal to Background Mean (Form 1)
Alternative Hypothesis	Site or AOC Mean Greater Than the Background Mean

Area of Concern Data: Hg(0 - 6in.)

Background Data: Hg(background)

Raw Statistics

	Site	Background
Number of Valid Samples	28	5
Number of Distinct Samples	23	5
Minimum	0.026	0.078
Maximum	4.03	3.88
Mean	1.632	1.288
Median	1.55	0.85
SD	1.033	1.524
SE of Mean	0.195	0.682

Site vs Background Two-Sample t-Test

H0: Mu of Site - Mu of Background <= 0

Method	DF	t-Test Value	Critical t (0.050)	P-Value
Pooled (Equal Variance)	31	0.64	1.696	0.264
Satterthwaite (Unequal Variance)	4.7	0.486	2.015	0.325

Pooled SD 1.109

Conclusion with Alpha = 0.050

* Student t (Pooled) Test: Do Not Reject H0, Conclude Site <= Background
* Satterthwaite Test: Do Not Reject H0, Conclude Site <= Background

Test of Equality of Variances

Numerator DF	Denominator DF	F-Test Value	P-Value
4	27	2.178	0.197

Conclusion with Alpha = 0.05

* Two variances appear to be equal

Results of Background Comparison
River Sediment - Mercury Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

t-Test Site vs Background Comparison for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference (S)	0
Selected Null Hypothesis	Site or AOC Mean Less Than or Equal to Background Mean (Form 1)
Alternative Hypothesis	Site or AOC Mean Greater Than the Background Mean

Area of Concern Data: Hg(6 - 18 in.)

Background Data: Hg(background)

Raw Statistics

	Site	Background
Number of Valid Samples	16	5
Number of Distinct Samples	14	5
Minimum	0.72	0.078
Maximum	4.7	3.88
Mean	2.307	1.288
Median	1.9	0.85
SD	1.162	1.524
SE of Mean	0.291	0.682

Site vs Background Two-Sample t-Test

H0: Mu of Site - Mu of Background <= 0

Method	DF	t-Test Value	Critical t (0.050)	P-Value
Pooled (Equal Variance)	19	1.595	1.729	0.064
Satterthwaite (Unequal Variance)	5.5	1.376	1.943	0.111

Pooled SD 1.247

Conclusion with Alpha = 0.050

* Student t (Pooled) Test: Do Not Reject H0, Conclude Site <= Background
* Satterthwaite Test: Do Not Reject H0, Conclude Site <= Background

Test of Equality of Variances

Numerator DF	Denominator DF	F-Test Value	P-Value
4	15	1.72	0.396

Conclusion with Alpha = 0.05

* Two variances appear to be equal

Results of Background Comparison
River Sediment - Mercury Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

t-Test Site vs Background Comparison for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference (S)	0
Selected Null Hypothesis	Site or AOC Mean Less Than or Equal to Background Mean (Form 1)
Alternative Hypothesis	Site or AOC Mean Greater Than the Background Mean

Area of Concern Data: Hg(18 - 30 in.)

Background Data: Hg(background)

Raw Statistics

	Site	Background
Number of Valid Samples	16	5
Number of Distinct Samples	13	5
Minimum	0.15	0.078
Maximum	3.7	3.88
Mean	1.879	1.288
Median	1.8	0.85
SD	1.075	1.524
SE of Mean	0.269	0.682

Site vs Background Two-Sample t-Test

H0: Mu of Site - Mu of Background <= 0

Method	DF	t-Test Value	Critical t (0.050)	P-Value
Pooled (Equal Variance)	19	0.975	1.729	0.171
Satterthwaite (Unequal Variance)	5.3	0.807	2.015	0.227

Pooled SD 1.184

Conclusion with Alpha = 0.050

* Student t (Pooled) Test: Do Not Reject H0, Conclude Site <= Background
* Satterthwaite Test: Do Not Reject H0, Conclude Site <= Background

Test of Equality of Variances

Numerator DF	Denominator DF	F-Test Value	P-Value
4	15	2.012	0.289

Conclusion with Alpha = 0.05

* Two variances appear to be equal

Results of Background Comparison
River Sediment - Mercury Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

t-Test Site vs Background Comparison for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference (S)	0
Selected Null Hypothesis	Site or AOC Mean Less Than or Equal to Background Mean (Form 1)
Alternative Hypothesis	Site or AOC Mean Greater Than the Background Mean

Area of Concern Data: Hg(30 - 42 in.)

Background Data: Hg(background)

Raw Statistics

	Site	Background
Number of Valid Samples	16	5
Number of Distinct Samples	11	5
Minimum	0.09	0.078
Maximum	3.1	3.88
Mean	1.603	1.288
Median	1.8	0.85
SD	1.066	1.524
SE of Mean	0.267	0.682

Site vs Background Two-Sample t-Test

H0: Mu of Site - Mu of Background <= 0

Method	DF	t-Test Value	Critical t (0.050)	P-Value
Pooled (Equal Variance)	19	0.523	1.729	0.304
Satterthwaite (Unequal Variance)	5.3	0.431	2.015	0.342

Pooled SD 1.178

Conclusion with Alpha = 0.050

* Student t (Pooled) Test: Do Not Reject H0, Conclude Site <= Background
* Satterthwaite Test: Do Not Reject H0, Conclude Site <= Background

Test of Equality of Variances

Numerator DF	Denominator DF	F-Test Value	P-Value
4	15	2.043	0.279

Conclusion with Alpha = 0.05

* Two variances appear to be equal

Results of Background Comparison
River Sediment - Mercury Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

Wilcoxon-Mann-Whitney Site vs Background Comparison Test for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference	0
Selected Null Hypothesis	Site or AOC Mean/Median Less Than or Equal to Background Mean/Median (Form 1)
Alternative Hypothesis	Site or AOC Mean/Median Greater Than Background Mean/Median

Area of Concern Data: Hg(0 - 6in.)

Background Data: Hg(background)

Raw Statistics

	Site	Background
Number of Valid Samples	28	5
Number of Distinct Samples	23	5
Minimum	0.026	0.078
Maximum	4.03	3.88
Mean	1.632	1.288
Median	1.55	0.85
SD	1.033	1.524
SE of Mean	0.195	0.682

Wilcoxon-Mann-Whitney (WMW) Test

H0: Mean/Median of Site or AOC <= Mean/Median of Background

Site Rank Sum W-Stat	498
WMW Test U-Stat	92
WMW Critical Value (0.050)	114
Approximate P-Value	0.14

Conclusion with Alpha = 0.05

Do Not Reject H0, Conclude Site <= Background

Results of Background Comparison
River Sediment - Mercury Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

Wilcoxon-Mann-Whitney Site vs Background Comparison Test for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference	0
Selected Null Hypothesis	Site or AOC Mean/Median Less Than or Equal to Background Mean/Median (Form 1)
Alternative Hypothesis	Site or AOC Mean/Median Greater Than Background Mean/Median

Area of Concern Data: Hg(6 - 18 in.)

Background Data: Hg(background)

Raw Statistics

	Site	Background
Number of Valid Samples	16	5
Number of Distinct Samples	14	5
Minimum	0.72	0.078
Maximum	4.7	3.88
Mean	2.307	1.288
Median	1.9	0.85
SD	1.162	1.524
SE of Mean	0.291	0.682

Wilcoxon-Mann-Whitney (WMW) Test

H0: Mean/Median of Site or AOC <= Mean/Median of Background

Site Rank Sum W-Stat	198
WMW Test U-Stat	62
WMW Critical Value (0.050)	60
Approximate P-Value	0.0379

Conclusion with Alpha = 0.05

Reject H0, Conclude Site > Background

Results of Background Comparison
River Sediment - Mercury Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

Wilcoxon-Mann-Whitney Site vs Background Comparison Test for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference	0
Selected Null Hypothesis	Site or AOC Mean/Median Less Than or Equal to Background Mean/Median (Form 1)
Alternative Hypothesis	Site or AOC Mean/Median Greater Than Background Mean/Median

Area of Concern Data: Hg(18 - 30 in.)

Background Data: Hg(background)

Raw Statistics

	Site	Background
Number of Valid Samples	16	5
Number of Distinct Samples	13	5
Minimum	0.15	0.078
Maximum	3.7	3.88
Mean	1.879	1.288
Median	1.8	0.85
SD	1.075	1.524
SE of Mean	0.269	0.682

Wilcoxon-Mann-Whitney (WMW) Test

H0: Mean/Median of Site or AOC <= Mean/Median of Background

Site Rank Sum W-Stat	190
WMW Test U-Stat	54
WMW Critical Value (0.050)	60
Approximate P-Value	0.132

Conclusion with Alpha = 0.05

Do Not Reject H0, Conclude Site <= Background

Results of Background Comparison
River Sediment - Mercury Data
Horseshoe Road/ARC OU3 Site
Sayreville, New Jersey

Wilcoxon-Mann-Whitney Site vs Background Comparison Test for Full Data Sets without NDs

User Selected Options

From File	C:\Documents and Settings\LHARRINGTON\Desktop\ARC\ARC Hg-As.wst
Full Precision	OFF
Confidence Coefficient	95%
Substantial Difference	0
Selected Null Hypothesis	Site or AOC Mean/Median Less Than or Equal to Background Mean/Median (Form 1)
Alternative Hypothesis	Site or AOC Mean/Median Greater Than Background Mean/Median

Area of Concern Data: Hg(30 - 42 in.)

Background Data: Hg(background)

Raw Statistics

	Site	Background
Number of Valid Samples	16	5
Number of Distinct Samples	11	5
Minimum	0.09	0.078
Maximum	3.1	3.88
Mean	1.603	1.288
Median	1.8	0.85
SD	1.066	1.524
SE of Mean	0.267	0.682

Wilcoxon-Mann-Whitney (WMW) Test

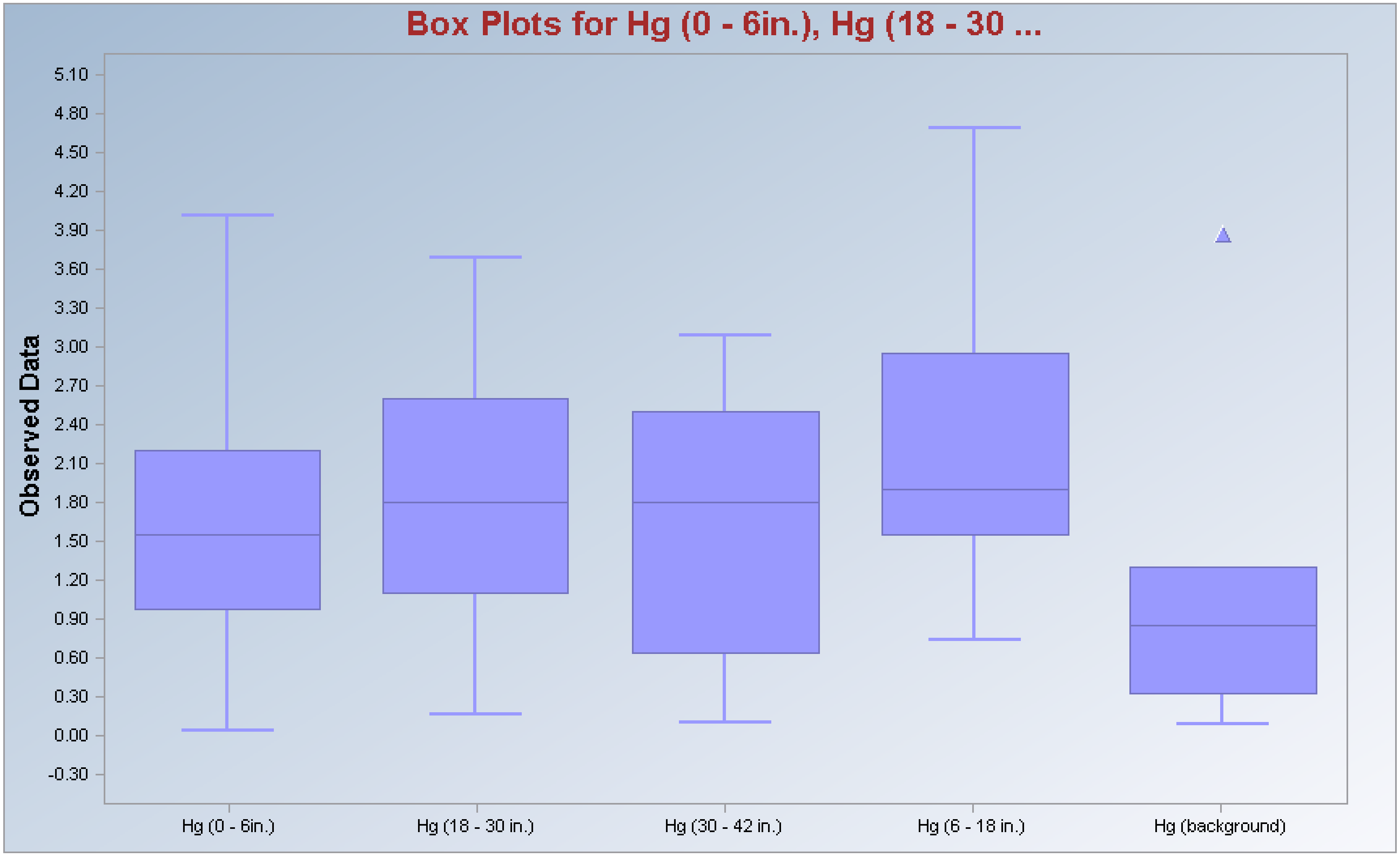
H0: Mean/Median of Site or AOC <= Mean/Median of Background

Site Rank Sum W-Stat	186
WMW Test U-Stat	50
WMW Critical Value (0.050)	60
Approximate P-Value	0.216

Conclusion with Alpha = 0.05

Do Not Reject H0, Conclude Site <= Background

Box Plots for Mercury



Quartile-Quartile Plots for Mercury